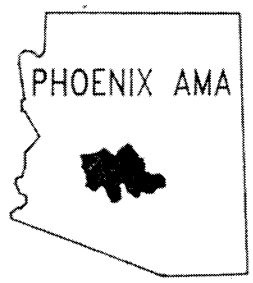
ARIZONA DEPARTMENT OF WATER RESOURCES

A REGIONAL GROUNDWATER FLOW MODEL OF THE SALT RIVER VALLEY - PHASE I

PHOENIX ACTIVE MANAGEMENT AREA

HYDROGEOLOGIC FRAMEWORK AND BASIC DATA REPORT



BY

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HYDROLOGY DIVISION

MODELING REPORT NO. 6

ARIZONA DEPARTMENT OF WATER RESOURCES

Phoenix, Arizona

April, 1993

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HYDROGEOLOGIC FRAMEWORK AND BASIC DATA REPORT

Final Report

by Edwin F. Corkhill, Steve Corell, Bradley M. Hill, and David A. Carr

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Hydrology Division - Groundwater Modeling Section

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Abstract

The Phoenix Active Management Area groundwater flow model focuses on the hydrologic system of the Salt River Valley, the most intensive water use area of the state. The goal of the hydrologic study and modeling effort was to develop a quantitative tool to test various groundwater management scenarios.

The predevelopment hydrologic system (circa 1900) of the Salt River Valley is analyzed. Various components of groundwater inflow and outflow are identified. A predevelopment groundwater budget is presented. The total inflows and outflows were in approximate balance and equaled approximately 139,000 acre-feet per year.

The modern hydrologic system (1978-1988) is analyzed. The various components of groundwater inflow and outflow are identified. Detailed descriptions of the methodologies used to analyze the components of flow are provided. A groundwater budget for the period 1978-1988 is presented. The total inflows were approximately 13.5 million acre-feet and the total outflows were approximately 14.0 million acre-feet. The estimated decrease in the volume of groundwater in storage was 0.5 million acre-feet.

Various recommendations are provided to improve future data collection and analysis efforts. The recommendations include: 1) development of a comprehensive aquifer test database to provide additional hydraulic conductivity data, 2) study the use of vertical extensometers and gravity change data to estimate storage properties of aquifers, 3) revision and enlargement of the Salt River Valley water level measurement index line, 4) improvement of the current stream gage network in the Salt River Valley.

Acknowledgements

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The analysis of geology and aquifer parameters was accomplished by David Carr and Nancy Beresky. The discussion of surface water resources was also provided by David Carr. Analysis and discussion of groundwater recharge was provided by Brad Hill, Lucinda Chavez, and Frank Corkhill. The discussion of the predevelopment and modern hydrologic systems, groundwater pumpage, and general editing were provided by Frank Corkhill. Preliminary modeling data and database management were provided by Steve Corell. Figures and illustrations were prepared by Paul Plato. Word processing was provided by Jo Ellen Woodall. Overall project supervision was the responsibility of Frank Putman.

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CHAPTER ONE. BACKGROUND ON MODEL DEVELOPMENT

I. INTRODUCTION

Arizona's Groundwater Management Act of 1980 was enacted to address the groundwater overdraft problem occurring in several areas of the state. The Act established the Arizona Department of Water Resources (ADWR), and also established four administrative areas in Arizona, known as Active Management Areas (AMAs), in which intensive groundwater management is required to address severe impacts on groundwater supplies due to extensive groundwater withdrawals. The groundwater flow model discussed in this report was designed to serve as a planning tool for groundwater management in the Phoenix AMA.

The Phoenix AMA, located in central Arizona, covers 5,646 square miles. The Phoenix AMA consists of seven groundwater sub-basins: East Salt River Valley (ESRV), West Salt River Valley (WSRV), Hassayampa, Rainbow Valley, Fountain Hills, Lake Pleasant, and Carefree. The ESRV and WSRV sub-basins are collectively referred to as the Salt River Valley (SRV). The focus of this modeling study is the SRV, the largest and most populous urban area in Arizona (Figure 1). Phoenix, the state's largest city, is centrally located in the SRV. The densely populated urban area extends several miles east and west of Phoenix and includes the cities of Tempe, Scottsdale, Mesa, Glendale, Chandler and Peoria, and many smaller cities and Indian communities. During the 1980 to 1985 period, the population of the SRV grew from 1,511,000 to 1,850,393 (ADWR, 1991).

Extensive water use occurs within the SRV. The combined water demand of the agricultural, municipal, and industrial sectors is the greatest of any area in the state. In 1988 the total estimated water use in the SRV was approximately 2.1 million acre-feet, of which approximately 1.0 million acre-feet was pumped groundwater (ADWR, 1992a). The total volume of groundwater pumped from the aquifers of the SRV between the early 1900's and 1984 was approximately 83 million acre-feet (USGS, 1986). Based on water level changes and assumed aquifer storativity it is estimated that the volume of groundwater in storage was reduced by approximately 23 million acre-feet during that period (ADWR, 1992b).

It is apparent that the historic trend in groundwater depletion, coupled with continued intensive demand on the groundwater system calls for careful management of the groundwater resources of the SRV. For these reasons the Phoenix AMA was established to reach a goal of safe-yield of the AMA's groundwater resources by 2025, or earlier. The ADWR has interpreted safe-yield to be the amount of groundwater that can be withdrawn without causing long-term aquifer depletions and water level declines. To achieve safe-yield the Phoenix AMA must develop a series of comprehensive and effective water management plans. To aid the Phoenix AMA in water management planning the modeling section of the Hydrology Division of the ADWR began the development of a three-dimensional groundwater flow model of the SRV area in November 1987.

The modeling effort has been divided into two phases. Phase I, documented in this report, consists of the hydrologic and geologic characterization of the study area. Phase I also includes a discussion of the methodologies used to compile and analyze groundwater recharge, pumpage, evapotranspiration, and underflow. Phase II will include the development and calibration of the numerical computer model, as well as recommendations for future modeling efforts. Phase II is currently underway.

II. GOAL AND OBJECTIVE OF THE MODELING EFFORT

The ultimate goal of the SRV groundwater modeling effort is to provide an analytical tool capable of quantifying the effects of various groundwater management and conservation scenarios on the groundwater resources within the study area. The objectives were: 1) perform a comprehensive search and collection of all current and historic hydrologic, geologic, and land use parameters, 2) develop a groundwater database of the assembled data, 3) develop a three-dimensional groundwater flow model, 4) develop recommendations concerning future data collection and model improvement efforts.

III. PURPOSE OF THE PHASE I REPORT

The purpose of the Phase I report is to document the data collection activities, and the analysis of the hydrogeologic data. The report also discusses the methodologies used in determining groundwater recharge, pumpage, evapotranspiration, and underflow.

IV. PREVIOUS INVESTIGATIONS

The first regional hydrologic and geologic studies in the SRV area were conducted around the turn of the century by the United States Geological Survey (USGS). Davis (1897) reported on irrigation and surface water supplies near Phoenix. Lippincott (1900) discussed the storage of water on the Gila River. The Lippincott report focused on the water supply and potential reservoir sites. The storage of water on the Salt River was investigated by Davis (1903). Lee (1904, 1905) reported on the underground waters of the Gila and Salt River Valleys. The Lee reports contain a wealth of historical information concerning well records, water level data, water quality data, along with excellent discussions of the geology and hydrology of the Gila and Salt River Valleys.

Several recent studies have contributed to the understanding of the modern hydrogeology of the area. In 1976 the United States Bureau of Reclamation (USBR) studied the geology and groundwater resources of Maricopa and Pinal Counties as a part of the Central Arizona Project (USBR, 1976). Ross (1978) produced maps showing groundwater conditions in the WSRV. Reeter and Remick (1983) produced maps showing groundwater conditions in much of the study area. Laney and Hahn (1986), and Brown and Pool (1989) reported on the hydrogeology of the ESRV and WSRV sub-basins, respectively. In addition to the reports mentioned there have been numerous local hydrologic and geologic studies conducted in the area. A useful reference for additional hydrologic reports on the area is the ADWR Bibliography of Selected Reports on Groundwater in Arizona (Remick, 1987).

Several groundwater modeling studies have been conducted in the region. Anderson (1968) constructed an electric analog model of the Central Arizona region. The Anderson model was used to analyze groundwater depletions projected for 1974 and 1984. Long and others (1982) constructed a digital, two-dimensional regional groundwater flow model of the SRV. The model was developed to aid in groundwater planning and management programs. Thomsen and Eychaner (1991) constructed a two-dimensional model of the predevelopment hydrologic system of the Gila River Indian Reservation. Thomsen and Porcello (1991) constructed a two-dimensional model of the predevelopment hydrogeologic system of the Salt River Indian Reservation. Both of the predevelopment models were developed to describe the hydrologic conditions that existed on the reservations prior to development by non-Indian settlers, and are useful to the understanding of the predevelopment groundwater system of the SRV which is discussed later in this report.

V. DATA SOURCES, DATA LIMITATIONS, AND PERIOD OF DATA COLLECTION

A wide variety of data sources have provided information for the modeling effort. Water level data and well construction data have been collected and compiled by the ADWR and the USGS, and were accessed through ADWR's wellsite and water level database, the Groundwater Site Inventory (GWSI) and ADWR's well registration database, the "55" Well File. Pumpage data were provided by various municipalities, irrigation districts, Indian communities, and the ADWR Registry of Groundwater Rights (ROGR) database. Geologic data were provided from geophysical logs, drillers' logs, geologists' logs, particle-size logs, gravity surveys, and other reports. USGS stream gage data and irrigation district reports on surface water deliveries and canal conditions were used to quantify various components of groundwater recharge. Irrigation data were supplied by aerial photo interpretation, and Landsat image analysis. Evapotranspiration data were provided from Landsat image analysis, and other reports. Each of these data sources are discussed in greater detail later in this report.

Although a wide variety of hydrologic, geologic, and water use data were available the data were limited in many parts of the study area. Water level data were limited or non-existent in many parts of the study area due to the lack of wells in non-agricultural or non-urban areas. Water level data were also limited temporally, since only a relatively small number water levels are measured in most years. Aquifer test data, and sub-surface geologic data were also lacking in many locations throughout the study area.

Hydrologic, geologic, and water use data were collected for the period 1978 through 1988. This period was selected due the greater availability of water level data and pumpage data. The period was also selected to provide continuity with previous modeling efforts which had compiled pumpage and recharge data through 1977 (Long and others, 1982).

CHAPTER TWO. HYDROGEOLOGIC SYSTEM

I. REGIONAL SETTING: GEOGRAPHY, PHYSIOGRAPHY, AND CLIMATE

The SRV is located in central Arizona (Figure 1). The study area of this report encompasses the heaviest water use area of the state and includes: the ESRV and WSRV sub-basins of the Phoenix AMA, and the northern portion of the Maricopa-Stanfield (MST) sub-basin of the Pinal AMA. Two major Indian communities are located within the study area . The Gila River Indian Community (GRIC) is located along the Gila River in the southern portion of the ESRV and northern portion of the MST sub-basin. The Salt River Pima-Maricopa Indian Community (SRPMIC) is located along the Salt River in the east-central section of the ESRV.

The study area is part of the Basin and Range physiographic province and consists of gently-sloping alluvial plains separated by predominantly north to northwest-trending mountain ranges (Anderson and others, 1990). Land surface elevations range from less than 800 feet above mean sea level at Gillespie Dam to over 6,000 feet above mean sea level in the Superstition Mountains. Elevations on the basin floors typically range from 1,000 to 2,500 feet above mean sea level.

The climate of the study area is semi-arid, with hot summers and mild winters. Average annual temperatures range from 71° F at Phoenix to 68° F at Carefree (Brazel and others, 1981). Average annual precipitation ranges from 7 inches to 8 inches, with higher elevations receiving more rainfall (ADWR, 1991). A small majority of the precipitation occurs in winter, however, July and August receive considerable amounts from thunderstorms associated with the summer monsoon.

The study area is drained by three major streams -- the Salt, Gila, and Agua Fria Rivers. The Salt River below Granite Reef Dam is ephemeral, flowing only in response to local flooding and releases from upstream reservoirs. The Gila River from Ashurst-Hayden Dam to near its confluence with the Salt River is also ephemeral, flowing only in response to flooding and reservoir releases. Below the confluence with the Salt River, the Gila River flows perennially due to effluent discharge from the City of Phoenix 91st Avenue Wastewater Treatment Plant. The Agua Fria River is ephemeral.

II. SOURCES OF GEOLOGIC DATA

The geology of the SRV was defined for the study using several types of subsurface data from various sources. These data were used to construct detailed cross-sections, make correlations, prepare structure contour maps, and assist in making preliminary estimates of hydraulic conductivity and specific yield for each hydrogeologic unit. The methodology used to define the geology of the SRV is outlined in the following sections.

Geologic data for the SRV study area include particle size data, driller's logs, monitor well logs from groundwater contamination sites, and logs from other sources. These data were obtained from various sources, including ADWR files, the USGS, the Arizona Oil and Gas Conservation Commission (AOGCC), and various water providers.

A. Particle Size Data

In the 1970s the USGS initiated a program of collecting cuttings samples from water wells drilled throughout the state. The samples were sieved and weighed at the USGS office in Tucson, and the data were compiled in paper and computer files. Although the program has been inactive for a number of years, the USGS now has an extensive database of particle size data from hundreds of wells within the major urban and agricultural areas of the state. Included within the files are estimated particle size information and geologist's logs, where available.

Particle size data were used extensively by Laney and Hahn (1986) and Brown and Pool (1989) in their hydrogeologic evaluations of the ESRV and WSRV, respectively. Approximately 350 particle size logs were available for the SRV, nearly all of which were used to define breaks between hydrogeologic units. Although the quality of particle size logs can vary considerably depending on the drilling method used, the particle size logs were generally considered to be the most reliable source of geologic data available for the study. For this reason, initial geologic interpretations were made using primarily this data source. Other types of data, such as driller's logs, were used to provide additional geologic definition in areas where particle size logs were unavailable.

B. Driller's Logs

Although driller's logs are commonly regarded as subjective and unreliable, they are very abundant in the SRV. The original SRV Two-Dimensional model (Long, and others, 1982) was developed from 1,788 selected driller's logs which were entered into a Driller's Log File on the ADWR computer system. The Driller's Log File was developed to facilitate geologic interpretation and develop aquifer parameters for the model.

Because the Driller's Log File represented an extensive collection of logs available in a format suitable for performing geologic evaluations, it was utilized as a significant source of geologic data for the study. Additional driller's logs were obtained from the well registry, or "55" file, and the old well registry, or "35" file, located at the ADWR Basic Data Section. These files were searched to obtain logs in areas with no available information, or in areas where available logs were of insufficient depth. Approximately 400 additional logs were obtained for this purpose, although not all were of sufficient quality to be used.

C. Monitor Well Logs

Approximately 60 logs from selected monitoring wells completed at most of the major groundwater contamination sites in the SRV were obtained from the files. These typically included both lithologic and geophysical logs and were generally of very good quality. Although groundwater contamination sites are located throughout most of the urbanized parts of the SRV, each site is relatively small. For this reason, these logs were only useful in small, selected areas.

D. Logs From Other Sources

Approximately 60 logs were obtained from other sources for use in completing the geologic evaluation. These included oil well logs from the Arizona Oil and Gas Conservation Commission, Central Arizona Project (CAP) test hole logs from the USBR, geophysical logs from the USGS, and lithologic and geophysical logs from several of the cities and major water providers.

Most of the oil well logs were of poor quality or were not suitable for interpreting lithologic breaks. However, a few oil well logs were of sufficient quality to provide this information. In addition, critical information concerning the depth to bedrock, and the depth to the top of the Luke salt body was also obtained from these logs.

All of the logs of test holes completed by the USBR as part of their hydrologic evaluation for the CAP were used. Although few in number, the test holes were distributed evenly throughout the SRV; most of the holes were completed to a depth of 2,000 feet. All of the holes were logged in detail and were cored at selected intervals; a few contained geophysical logs as well.

Approximately 20 geophysical logs were obtained from the USGS, which had compiled the logs from various sources. Very few of these geophysical logs were useful, as corresponding lithologic logs were not available.

A number of lithologic and geophysical logs of water supply wells maintained by the cities, major water providers, and irrigation districts were obtained, either directly from the source or from ADWR files. Entities which provided geologic data to the study included the City of

Phoenix, the Salt River Project, the City of Scottsdale, the Roosevelt Irrigation District, and the Roosevelt Water Conservation District, among others.

III. HYDROGEOLOGIC SETTING

The hydrogeologic setting of the Salt River Valley (SRV) is described in reports by Laney and Hahn (1986) on the hydrogeology of the eastern part of the SRV and Brown and Pool (1989) on the hydrogeology of the western part of the SRV. Part of the information presented in this section was obtained from these sources. The remainder is from studies by the authors of this report.

A. Structure

The SRV consists of two distinct but interconnected alluvial groundwater basins. The western alluvial basin is approximately equivalent to the West Salt River Valley (WSRV) subbasin of the Phoenix AMA; the eastern alluvial basin includes the East Salt River Valley (ESRV) sub-basin of the Phoenix AMA and the northern part of the Maricopa Stanfield (MST) sub-basin of the Pinal AMA. The alluvial basins are connected between South Mountain and the Estrella Mountains and between South Mountain and the Papago Buttes (see Figure 1).

The alluvial basins are defined and partially surrounded by predominantly north to northwest trending fault-block mountain ranges. The alluvial basins and most of the surrounding mountains characteristic of present-day Basin and Range physiography were formed during a period of high-angle block faulting that occurred between approximately 15 and 8 million years ago (Shafiqullah and others, 1980). South Mountain is a northeast-trending arch structure that was formed prior to Basin and Range faulting (Reynolds, 1985).

B. Hydrologic Bedrock Unit

The rocks that form the mountain ranges surrounding the alluvial basins are composed predominantly of crystalline rocks of Precambrian to middle Tertiary age and extrusive rocks of middle Tertiary to Quaternary age (Brown and Pool, 1989). The crystalline and extrusive rocks form nearly impermeable boundaries to groundwater flow and are collectively referred to in this report as the hydrologic bedrock unit.

The crystalline rocks of the hydrologic bedrock unit are composed of various metamorphic and granitic rocks, including schist, gneiss, metavolcanics, quartzite, granite and other granitic rocks of Precambrian to middle Tertiary age. The extrusive rocks include middle to late Tertiary volcanic rocks of rhyolitic to basaltic composition and basalt flows of middle Tertiary to Quaternary age. The hydrologic bedrock unit may locally contain and transmit small quantities of water where fractured, but is not regarded as an aquifer on a regional scale.

C. Red Unit

The mountain ranges surrounding the basins also include sedimentary rocks of Late Tertiary age referred to as the red unit (Arteaga and others, 1968). The red unit has also been referred to in the literature as the Tempe beds (Schulten and others, 1979) and the Camel's Head Formation (Cordy and others, 1978). The red unit occurs at Mount McDowell and the Papago Buttes, and in the subsurface in east Phoenix and Scottsdale.

The red unit consists of reddish-colored, well-cemented breccia, conglomerate, sandstone and siltstone (Laney and Hahn, 1986). The breccia and conglomerate are poorly sorted, with particle sizes ranging from clay to boulders up to 15 feet in diameter. The sandstone and siltstone are better sorted and stratified. The upper part of the unit locally contains interbedded volcanic flows and pyroclastic rocks. The red unit has been interpreted as consisting primarily of alluvial fan deposits.

The red unit was deposited prior to the high-angle normal faulting that formed the alluvial basins. The origin of the unit at the Papago Buttes may be related to the development of the South Mountain arch structure (Reynolds, 1985). The age of the red unit may range from 17.5 to 22 million years, based on radiometric dating of volcanic rocks within the unit (Brown and Pool, 1989).

Because the red unit is limited in areal extent and typically well-cemented, it is not a significant source of water on a regional scale. In Paradise Valley, however, the unit yields more water to wells than do the overlying units, probably due to fracturing and faulting (Arteaga and others, 1968). The red unit has therefore been included with the basin-fill deposits for modeling purposes.

D. Basin-Fill Deposits

The alluvial basins of the SRV consist of thick basin-fill deposits of unconsolidated to semiconsolidated clastic sediment of Late Tertiary to Quaternary age. Radiometric dating of volcanic rocks within the basin fill suggest that the basin-fill deposits were formed between 15.8 and 3.3 million years ago (Laney and Hahn, 1986).

The basin-fill deposits range in thickness from less than 100 feet near the basin margins to over 10,000 feet in the central areas of the basins (Figure 2). The thickest basin-fill deposits in the WSRV are near Luke Air Force Base, where the structure and lithology of the basin-fill deposits have been influenced by a massive evaporite deposit referred to as the Luke Salt Body (Eaton, Peterson and Schumann, 1972). The thickest basin-fill deposits in the ESRV occur east of Gilbert, where a total thickness of over 9,000 feet has been recorded by geothermal exploration drilling. The basin-fill deposits in the ESRV also exceed 7,000 feet in thickness east of Scottsdale and 5,000 feet in thickness east of the Union Hills.

The basin-fill deposits consist of interbedded sequences of conglomerate, gravel, sand, silt, clay and evaporites. These clastic sediments represent sequences of alluvial fan, playa and fluvial deposits formed during the development of the alluvial basins. In general, the basin-fill deposits become finer-grained toward the central areas of the alluvial basins and tend to coarsen upward. These observed lithologic relationships are interpreted as representing alluvial fan and playa deposits formed in closed basins during the early and middle stages of basin development, followed by fluvial and alluvial fan deposits formed during the late stages of basin development after the establishment of through-flowing drainages.

The basin-fill deposits comprise the regional aquifer in the SRV and are the primary focus of the modeling effort. Individual hydrogeologic units within the basin-fill deposits have been defined for the model, as discussed in the following sections.

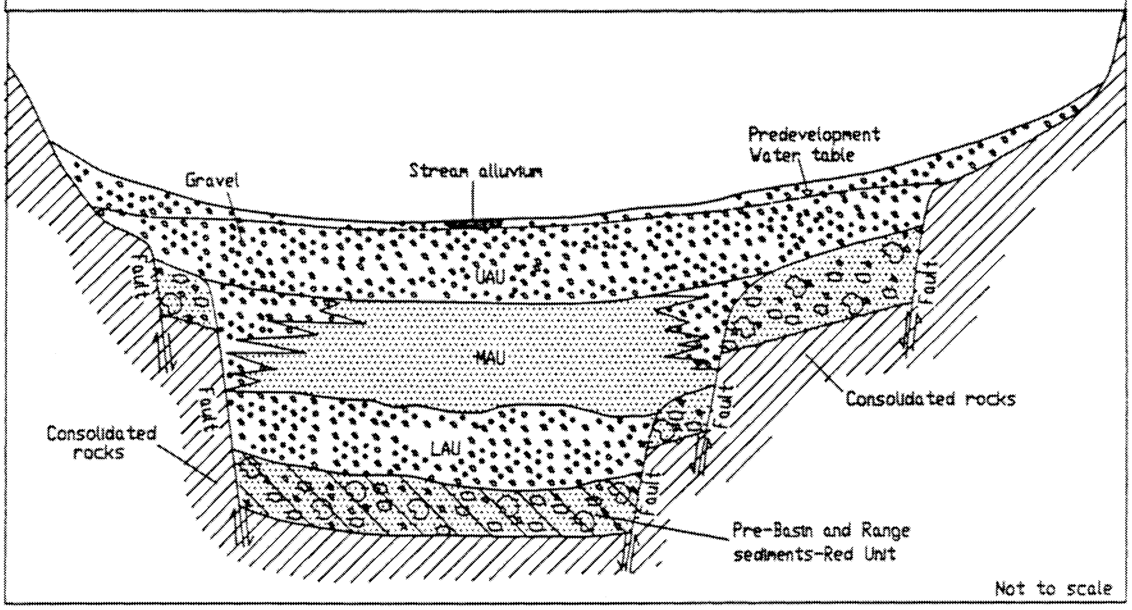
IV. HYDROGEOLOGIC UNITS DEFINED FOR THE MODEL

A. Definition of Hydrogeologic Units

An evaluation of available geologic information during the early stages of data development indicated that the basin-fill deposits are characterized in most areas by a lower unit consisting mainly of conglomerate and gravel, a middle unit consisting predominantly of silt and clay, and an upper unit consisting mainly of gravel and sand. The units were defined using particle size data and lithologic data, where available. Because these three units are characterized by unique hydraulic properties, the basin-fill deposits were subdivided into three hydrogeologic units for modeling purposes. The three hydrogeologic units are designated, in ascending order: (1) Lower Alluvial Unit (LAU), (2) Middle Alluvial Unit (MAU) and (3) Upper Alluvial Unit (UAU). The stratigraphic relationships among the three hydrogeologic units of the basin-fill deposits, the red unit and the hydrologic bedrock unit are presented in Figure 3.

These three hydrogeologic units are partially equivalent to similar units defined in previous investigations by the USBR (1976) and the USGS (Laney and Hahn, 1986; Brown and Pool, 1989). There are, however, differences in definition of hydrogeologic units between the USBR, USGS and ADWR based on the objectives of each investigation.

Figure 3
Generalized Cross-Section of the Principal Hydrogeologic Units of the SRV



Bedrock Faulting adapted from Anderson, and others, 1990

The USBR recognized three hydrogeologic units in their evaluation of the geology and groundwater resources of Maricopa and Pinal counties for the Central Arizona Project. The hydrogeologic units defined by the USBR were designated Upper Alluvial Unit, Middle Fine-Grained Unit and Lower Conglomerate Unit. In many locations, the breaks between hydrogeologic units defined by the USBR are similar to those defined in the current investigation. In other locations, they are significantly different. In general, the UAU defined by the USBR tends to be thicker than the UAU defined in the current investigation.

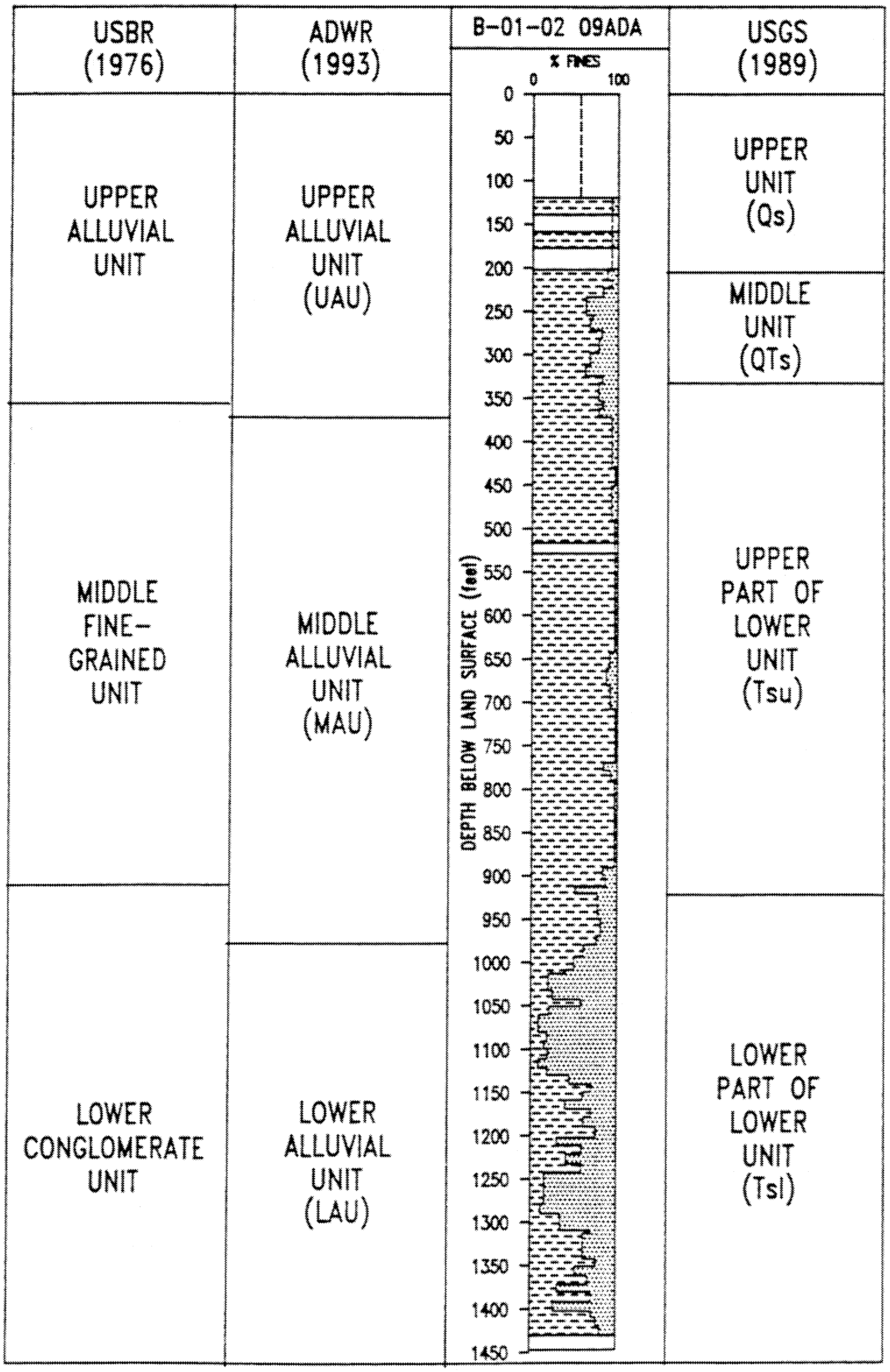
The USGS also recognized three hydrogeologic units in their evaluations of the hydrogeology of the ESRV (Laney and Hahn, 1986) and the WSRV (Brown and Pool, 1989). However, the hydrogeologic units defined by the USGS are significantly different from the hydrogeologic units defined for the current investigation. In addition to using particle size data to define hydrogeologic units, the USGS also used detailed lithologic descriptions obtained by inspecting the drill cuttings used to develop the particle size data. As a result, the hydrogeologic units defined by the USGS were defined as both geologic and hydrogeologic units.

In general, the upper unit defined by the USGS (Qs) is approximately equivalent to the upper part of the UAU. The middle unit defined by the USGS (QTs) is approximately equivalent to the lower part of the UAU and, in some locations, the upper part of the MAU. the lower unit defined by the USGS has been subdivided into an upper part (Tsu) and a lower part (Tsl). The upper part of the lower unit is approximately equivalent to most or all of the MAU; the lower part of the lower unit is approximately equivalent to the LAU.

Figure 4 illustrates the differences in definition of hydrogeologic units between the USBR, ADWR and USGS for a particle-size log from an irrigation well located at B-01-02 9ada2.

FIGURE 4

EXAMPLE PARTICLE-SIZE LOG WHICH SHOWS THE CORRELATION BETWEEN ADWR HYDROGEOLOGIC UNITS, USGS, AND USBR GEOLOGIC UNITS



Differences in definition between the USBR and ADWR at this location are primarily over nomenclature. Differences between the USGS and ADWR concern definition of units as well as nomenclature.

The three hydrogeologic units defined for this investigation are recognized in all areas except: (1) in the northern part of the WSRV near the Hedgpeth Hills and Hieroglyphic Mountains, (2) in the northern part of the ESRV northeast of the Union Hills, (3) in the eastern part of the ESRV near the Superstition Mountains, (4) in the southern part of the ESRV between the Sacaton and Santan mountains, and (5) near most mountain fronts. In areas where the three hydrogeologic units are difficult or impossible to recognize, boundaries between units have been inferred for modeling purposes.

B. Lower Alluvial Unit (LAU)

The Lower Alluvial Unit (LAU) overlies or is in fault contact with the hydrologic bedrock unit and the red unit. The LAU consists mainly of conglomerate and gravel near the basin margins, grading into mudstone, gypsiferous and anhydritic mudstone and anhydrite in the central areas of the basins. The LAU locally contains interbedded volcanic rocks. Radiometric dating of volcanic rocks within the LAU indicates that the unit may be as old as 16.6 million years (Brown and Pool, 1989).

An isopach map of the LAU is presented in Figure 5. The LAU may be less than 100 feet thick near the basin margins and several thousands of feet thick in the central areas of the basins. Due to a lack of deep drilling data, no attempt was made to map the thickness of the

LAU below 3,000 feet, the assigned maximum depth of the model. For this reason, the LAU appears to attain a maximum thickness of 2,000 feet in the central areas of the basin - the true thickness of the LAU is unknown.

A bottom elevation contour map of the LAU is presented in Figure 6. This map is essentially a structure contour map of the top of the hydrologic bedrock unit, and shows a pattern similar to the depth to bedrock map presented in Figure 2. As with the isopach map, no attempt was made to map the bottom elevation of the LAU below 3,000 feet.

Figures 5 and 6 both show the effects of the Luke Salt Body on the thickness and structure of the upper part of the LAU. The Luke Salt Body is interpreted as having formed as an evaporite deposit during deposition of the LAU. Movement of the Luke Salt Body has had a noticeable effect on the thickness and structure of both the LAU and the overlying MAU. Although available data indicate that the Luke Salt Body is part of the LAU, it is considered to represent a hydraulic barrier and has been included within the hydrologic bedrock unit for modeling purposes.

The LAU was deposited during the early stages of development of the alluvial basins. The increasing thickness and decreasing particle size of the LAU with increasing distance from the mountain fronts suggest that the alluvial basins were closed and subsiding during deposition of the unit. The LAU is interpreted as consisting of alluvial fan deposits near the mountain fronts grading into fluvial, playa and evaporite deposits in the central areas of the basins. Sediment within the unit was probably derived from the surrounding mountains.

A significant amount of the groundwater pumped from the peripheral areas of the ESRV and WSRV is derived from the LAU. It is estimated that approximately 25 percent of the total pumpage originates from the unit (ADWR, 1992b). The potential yield to wells completed in the LAU ranges from 50 to 3,500 gpm, with the highest yields from wells in locations where the LAU is coarser-grained. Most of the recoverable groundwater occurs within the upper 500 feet of the unit. Hydraulic conductivity estimates for the LAU range from about 5 to 60 feet/day, based on aquifer test results and specific capacity data. Specific yield estimates for the unit range from about 3 to 15 percent.

C. Middle Alluvial Unit (MAU)

The Middle Alluvial Unit (MAU) overlies the LAU. The MAU consists mainly of clay, silt, mudstone and gypsiferous mudstone with some interbedded sand and gravel. Near the margins of the alluvial basins the MAU consists mainly of sand and gravel and is difficult or impossible to distinguish from the other units.

An isopach map of the MAU is presented in Figure 7. In general, the MAU thickens toward the central areas of the basin. The unit may be less than 100 feet thick near the basin margins and over 1,600 feet thick in the deeper parts of the basins. In the ESRV, the MAU is thickest southeast of Gilbert, an area which corresponds to the deepest part of the basin. In the WSRV, the MAU is thickest south and east of the Luke Salt Body.

A bottom elevation contour map of the MAU is presented in Figure 8. This map shows a pattern similar to the isopach map of the MAU (Figure 7). Figures 5 and 6 both show the effects of the Luke Salt Body on the thickness and structure of the MAU.

The MAU was deposited during the middle stages of development of the alluvial basins. The increasing thickness and decreasing particle size of the MAU with increasing distance from the mountain fronts suggest that the alluvial basins were still closed and subsiding during deposition of the unit. Like the LAU, the MAU is interpreted as consisting of alluvial fan deposits near the mountain fronts grading into fluvial, playa and evaporite deposits in the central areas of the basins. The lithology of the MAU consists predominantly of silt and clay, however, which suggests that the unit consists primarily of playa deposits. Sediment within the unit was probably derived from the surrounding mountains.

The MAU is the primary source of groundwater in the study area. It is estimated that approximately 50 percent of the total pumpage in the study area is derived from the MAU (ADWR, 1992b). The potential yield to production wells completed in the MAU ranges from 350 to 2,200 gpm. Much of the recoverable groundwater in the unit may originate from the interbedded sand and gravel layers within the unit. Hydraulic conductivity estimates for the MAU range from about 5 to 50 feet/day, based on aquifer test results and specific capacity data. Specific yield estimates for the unit range from about 3 to 14 percent.

D. Upper Alluvial Unit (UAU)

The Upper Alluvial Unit (UAU) overlies the MAU. The UAU consists mainly of gravel, sand and silt. The composition of the UAU is dominated by gravel and sand near the present-day Salt and Gila rivers, near the former course of the Salt River east and south of South Mountain, and near the margins of the alluvial basins. In other areas, the unit is typically dominated by sand and silt.

An isopach map of the UAU is presented in Figure 9. The thickness of the UAU is relatively uniform and does not show the same trends characteristic of the MAU and LAU. The UAU is typically between 200 and 300 feet thick in the ESRV and between 300 and 400 feet thick in the WSRV. The unit is between 100 and 200 feet thick near the Salt and Gila rivers and becomes thinner near mountain fronts.

A bottom elevation contour map of the UAU is presented in Figure 10. Because of the relatively uniform thickness of the unit, the bottom elevation contours tend to resemble land surface elevation contours.

The UAU was deposited during the final stages of development of the alluvial basins. The relatively uniform thickness of the unit and association of coarser-grained sediments with the locations of major drainages suggest that the unit was deposited by the ancestral Salt and Gila rivers after the establishment of through-flowing drainages. Deposition also occurred from alluvial fans along mountain fronts. The UAU is interpreted as consisting of alluvial channel, terrace, floodplain and alluvial fan deposits. Sediment within the unit was derived from the ancestral Salt and Gila rivers and other streams, and from the surrounding mountains.

The UAU was once the primary source of groundwater in the study area, but is now dewatered in many areas due to groundwater withdrawal. It is estimated that approximately 25 percent of the total pumpage in the study area is now derived from the UAU (ADWR, 1992b). The potential yield to wells completed in the UAU ranges from 1,500 to 5,500 gpm. Hydraulic conductivity estimates for the UAU have been obtained from aquifer test results and specific capacity data. The hydraulic conductivity of the UAU ranges from about 20 to 250 feet/day and is highest near the Salt and Gila rivers. Specific yield estimates for the unit range from about 8 to 22 percent.

E. Hydrogeologic Cross Sections

Five hydrogeologic cross-sections have been prepared to illustrate stratigraphic relationships among the three hydrogeologic units of the basin-fill deposits and the hydrologic bedrock unit across the study area. Locations of the cross-sections are presented in Figure 11; the cross-sections are presented in Figures 12 through 16. These relationships are probably best illustrated in Figure 12, a hydrogeologic cross-section that extends from the White Tank Mountains in the west to the Superstition Mountains in the east and includes the Phoenix metropolitan area. Figure 12 represents a complete hydrogeologic cross-section of the SRV and shows the WSRV and ESRV as distinct alluvial groundwater basins separated for the most part by relatively impermeable bedrock. Figures 13 through 16 illustrate stratigraphic relationships among hydrogeologic units in other parts of the study area.

V. LAND SUBSIDENCE, EARTH FISSURING AND AQUIFER SYSTEM COMPACTION

Land subsidence, earth fissuring, and aquifer system compaction occurs in the study area near locations of significant groundwater withdrawals. As water levels decline subsidence and aquifer compaction can occur. Localized differential subsidence, fissures, and faults are most likely to occur near the edges of a basin where compaction may be greatly influenced by the depth and geometry of bedrock. Differential compaction of the aquifer in such places may cause the land surface to bend across prominent bedrock features; the accompanying tensile stresses may result in fissuring (Anderson, 1988).

Groundwater pumping has resulted in land subsidence and the development of earth fissures in the Queen Creek, Paradise Valley, and Luke Air Force Base areas (Schumann and Genualdi, 1986). In the Queen Creek area, an area of approximately 230 square miles north of the Santan Mountains had subsided more than 3 feet by 1977. Over 5 feet of land subsidence occurred east of Mesa between 1948 and 1981. As much as 5 feet of land subsidence occurred in the Paradise Valley area between 1965 and 1982. Differential subsidence over a buried bedrock hill resulted in a 400 foot long fissure in a northeast Phoenix construction site in 1980 (Larson and Pewe, 1986). An area of 140 square miles near Luke Air Force Base had subsided more than 3 feet by 1977. All of these areas are characterized by extensive historic groundwater pumpage and water level declines.

Aquifer system compaction due to water level declines is also of considerable concern in the study area. The impact of compaction on basin hydrology is mainly the permanent loss of aquifer storage (Anderson and others, 1990). The volume of lost storage within the aquifer is equal to the volume of land subsidence. Inelastic compaction of fine-grained sediments occurs over a long period of time and a large volume of water is released from storage as a result of this inelastic compaction (Anderson and others, 1990). Unfortunately, this is a one-time release of water from the aquifer, and the loss in storage is irreversible.

CHAPTER THREE. SURFACE WATER SYSTEM

I. GENERAL BACKGROUND

The SRV study area is drained by the Gila River and four principal tributaries: the Salt, Verde, Agua Fria, and Hassayampa Rivers. Other tributaries include Queen Creek, New River, Skunk Creek, Cave Creek, Waterman Wash, and Centennial Wash (Putman, 1983). Surface water flow data are summarized in Table 1. The locations of major rivers, streams and streamgaging stations are shown in Figure 17.

A. Gila River

The Gila River, which originates in western New Mexico and enters Arizona near Duncan, drains most of southern and central Arizona. The river enters the study area between the Santan and Sacaton Mountains near Sacaton, flows northwest and west near the Sierra Estrella Mountains and the Buckeye Hills, and exits the area at Gillespie Dam. Prior to 1890, the Gila River flowed perennially through the area (Lee, 1904). Now largely ephemeral, the river is currently regulated by Coolidge Dam and Ashurst-Hayden Dam located east of Florence. The dams store and divert water for the San Carlos Irrigation Project. In addition, groundwater pumping has lowered the water table, removing any base flow component from the Gila River.

Between Ashurst-Hayden Dam and Gila Crossing (Township 2 South, Range 2 East, Section 9), the Gila River is ephemeral, flowing mainly in response to flooding or reservoir releases. Between Gila Crossing and its confluence with the Salt River the Gila River becomes perennial as groundwater underflow returns to the river channel. The average annual flow of the Gila River near Laveen was approximately 24,000 acre-feet per year from 1941-1990. The median annual flow was approximately 7,700 acre-feet per year (USGS, 1991).

Table 1
Annual Flows For USGS Streamgaging Station In The Phoenix AMA
(Figures Rounded to Nearest 100 AF)

Station Name	*Station Number (1)*	*Period of Record*	*Mean Annual Flow (ac-ft)*	*Median Annual Flow (ac-ft)*	*Record Annual High Flow (ac-ft)*	*Record Annual Low Flow (ac-ft)*
Gila River near Laveen	9479500	1941-1946, 1949-1990	24,000	7,700	207,100	0
Queen Creek at Whitlow Dam	9478500	1949-1958	3,000	2,100	9,800	900
Salt River below Stewart Mountain Dam	9502000	1935-1990	708,000	597,300	2,557,760	203,200
Salt River below Granite Reef Dam	9511500	1952-1992	280,000	5,900	2,061,400	0
Verde River above Salt River confluence	9511300	1962-1990	456,400	338,800	1,335,900	109,700
Cave Creek north of Arizona Canal	9512400	1958-1990	2,600	800	18,300	0
Agua Fria River at Avondale	9513970	1968-1972, 1974-1982	15,300	700	168,700	0
New River at New River	9513800	1961-1982	10,000	2,300	53,400	0
New River at Bell Road	9513835	1968-1984	8,500	2,300	35,200	0
Skunk Creek near Union Hills	9513860	1968-1990	1,200	500	6,213	0
Centennial Wash at Arlington	9517490	1981-1984, 1990	2,300	1,400	7,000	100
Santa Cruz River near Laveen	9489000	1941-1946, 1949-1990	17,700	6,200	123,000	900

(1) Source of streamgage data (USGS, 1991). Streamgage data for gage 9511500 supplied by the Salt River Project (SRP, 1993a).

Below the confluence with the Salt River, the Gila River flows perennially for about 40 miles before reaching Gillespie Dam (Brown, and others, 1977). The perennial flows are due to effluent discharge in the Salt River from the City of Phoenix 23rd and 91st Avenue wastewater treatment plants. Much of this water is diverted for agricultural irrigation by the Buckeye Irrigation Company and the Arlington Canal Company. Water is also diverted for the Palo Verde Nuclear Generating Station near Wintersburg. The remaining water exits the area at Gillespie Dam. The average annual flow of the Gila River at Gillespie Dam was 287,600 acre-feet per year from 1935-1989 (Boner and others, 1989).

B. Queen Creek

Queen Creek is an ephemeral stream that begins in the Superstition Mountains a few miles north of Superior and flows west into the study area near Florence Junction. Queen Creek once flowed into the Gila River but now ends at the Roosevelt Water Conservation District (RWCD) Canal north of the Santan Mountains. Queen Creek is partly regulated by Whitlow Dam, an earthen flood control structure located about ten miles west of Superior. Flow information for Queen Creek is limited to a partial record at Whitlow Dam. The average annual flow of Queen Creek was approximately 3,000 acre-feet from 1949-1958. The median annual flow was approximately 2,100 acre-feet per year (USGS, 1991).

C. Salt River

The Salt River, which originates in eastern Arizona, drains approximately 6,000 square miles of the Mogollon Rim area in the east-central part of the state. The Salt River enters the study area north of the Goldfield Mountains and flows southwest, through the cities of Mesa, Tempe, and Phoenix, and into the Gila River near Laveen. Like the Gila River, the Salt River also flowed perennially before the late 1800s (Lee, 1905). Flow in the Salt River is currently regulated by a system of five dams for water supply, hydroelectric power, and flood control.

Stewart Mountain Dam, which forms Saguaro Lake, is located east of the study area between Stewart Mountain and the Goldfield Mountains. Flow in the Salt River is perennial below the dam. The average annual flow of the Salt River below Stewart Mountain Dam was 708,000 acre-feet from 1935-1990 (USGS, 1991). The median annual flow was approximately 597,300 acre-feet per year (USGS, 1991).

Granite Reef Dam is located approximately 10 miles downstream from Stewart Mountain Dam, between Sawik Mountain and the Usery Mountains. Water reaching the dam consists of the combined flows of the Salt and Verde Rivers, which averaged 1,249,000 acre-feet per year from 1961-1980 (Putman, 1983). Granite Reef Dam diverts almost all of the Salt and Verde river flows into the Salt River Project (SRP) canal system for agricultural, municipal, and industrial water use. Downstream from the dam, most of the Salt River is ephemeral, flowing mainly in response to flooding or reservoir releases. The average annual flow of the Salt River below Granite Reef Dam was 299,500 acre-feet from 1952-1986 (SRP, 1987). The median annual flow was approximately 5,000 acre-feet per year. The relatively high average annual value is attributed to 5 years in the 35 year period with spills in excess of 1,000,000 acre-feet. Approximately the last 8 miles of the Salt River are perennial (Brown and others, 1977) due to effluent discharge from the City of Phoenix 23rd and 91st Avenue wastewater treatment plants.

D. Verde River

The Verde River, which originates in Chino Valley north of Prescott, is a perennial river that drains approximately 7,000 square miles of central Arizona, from Seligman to Fort McDowell. The Verde River is regulated by Horseshoe Dam and Bartlett Dam. Both dams are located northeast of the study area near the western edge of the Mazatzal Mountains. The Verde River flows south through the Fountain Hills sub-basin, joining the Salt River between Stewart Mountain Dam and Granite Reef Dam. Tributaries include Camp Creek, an intermittent stream that flows into the Verde from the northwest, and Sycamore Creek, an intermittent stream that flows into the Verde from the east. The average annual flow of the Verde River above the confluence with the Salt River was 456,400 acre-feet from 1962-1990. The median annual flow was approximately 338,800 acre-feet per year (USGS, 1991).

E. Cave Creek

Cave Creek is an ephemeral stream that originates east of New River Mesa and flows southwest near the town of Cave Creek, across the northern part of Paradise Valley and into Deer Valley in northwest Phoenix. The drainage area of Cave Creek is approximately 250 square miles. Cave Creek once flowed into the Salt River but now ends at the Arizona Canal Diversion Channel in northwest Phoenix. Cave Creek is regulated by Cave Buttes Dam, an earthen flood control structure north of the Union Hills. The average annual flow of Cave Creek north of the Arizona Canal was 2,600 acre-feet from 1958-1990 (USGS, 1991). The median annual flow was approximately 800 acre-feet per year (USGS, 1991).

F. Agua Fria River

The Agua Fria River, an intermittent to ephemeral stream that heads northeast of Prescott, drains part of central Arizona between Prescott and Phoenix. The Agua Fria enters the study area approximately 20 miles north of Peoria, flows south along the western edge of the Phoenix metropolitan area and joins the Gila River south of Avondale. The drainage area of the Agua Fria River and tributaries is approximately 2,000 square miles.

The Agua Fria River is regulated by the new Waddell Dam, which forms Lake Pleasant. Almost all of the water from Lake Pleasant is diverted at a downstream diversion dam into the Beardsley Canal by the Maricopa Water District (MWD). Annual diversions into the Beardsley Canal averaged approximately 28,000 acre-feet from 1959-1975. Downstream from the dam, the Agua Fria River is ephemeral, flowing mainly in response to flooding or reservoir releases. The average annual flow of the Agua Fria River near Avondale, which includes additions to flow from New River and Skunk Creek, was approximately 15,300 acre-feet from 1968-1982 (USGS, 1991). The median annual flow was approximately 700 acre-feet per year (USGS, 1991).

G. New River

New River is an ephemeral stream that begins north of the study area in the New River Mountains. New River flows southwest near the town of New River, across the Lake Pleasant sub-basin and into the Salt River Valley, joining the Agua Fria River east of Litchfield Park. The drainage area of New River is approximately 320 square miles. New River is regulated by New River Dam, a recently completed earthen flood control structure north of the Hedgpeth Hills. The average annual flow of New River at New River was approximately 10,000 acre-feet from 1961-1982 (USGS, 1991). The median annual flow was approximately 2,300 acre-feet per year (USGS, 1991). The average annual flow at Bell Road near Peoria was approximately 8,500 acre-feet from 1968-1984 (USGS, 1991). The median annual flow was approximately 2,300 acre-feet per year (USGS, 1991).

H. Skunk Creek

Skunk Creek is a relatively small ephemeral stream that begins near the southern end of the New River Mountains. Skunk Creek flows south, passing between the Deem and Union hills and around the southern end of the Hedgpeth Hills, and joins New River near Peoria. The drainage area of Skunk Creek at the gaging station is approximately 65 square miles. Skunk Creek is regulated by an earthen flood control structure between Adobe Mountain and the southern end of the Hedgpeth Hills. The average annual flow of Skunk Creek near the Union

Hills was approximately 1,200 acre-feet from 1968-1990 (USGS, 1991). The median annual flow was approximately 500 acre-feet per year (USGS, 1991).

I. Waterman Wash

Waterman Wash is an unregulated ephemeral stream that drains the Rainbow Valley sub-basin. Waterman Wash heads approximately 10 miles west of the town of Mobile and flows northwest, joining the Gila River east of Buckeye. The drainage area of Waterman Wash is approximately 420 square miles. The average annual flow of Waterman Wash is unknown, but is believed to be quite small (Putman, 1983).

J. Hassayampa River

The Hassayampa River originates in the Bradshaw Mountains south of Prescott and drains an area of approximately 1,470 square miles in west-central Arizona. The Hassayampa enters the study area approximately 5 miles north of Morristown, flows south across the Hassayampa sub-basin and joins the Gila River east of Arlington.

Within the study area, the Hassayampa River is ephemeral and unregulated. North of the study area the Hassayampa River is perennial at the Box Dam site, about five miles northeast of Wickenburg. The average annual flow at the Box Dam site was approximately 17,700 acre-feet from 1947 to 1982 (USGS, 1991). The median annual flow was approximately 6,200 acre-feet (USGS, 1991).

K. Centennial Wash

Centennial Wash is a large ephemeral stream that drains an area of approximately 1810 square miles in western Arizona. Centennial Wash begins a few miles north of Aguila, flows southwest through McMullen Valley, then southeast across the Harquahala Plain. Centennial Wash enters the study area between the Palo Verde Hills and the Gila Bend Mountains and joins the Gila River near Arlington. Centennial Wash is largely unregulated except for a few irrigation diversions. The average annual flow of Centennial Wash near Arlington was approximately 2,300 acre-feet from 1981-1990 (USGS, 1991). The median annual flow was approximately 1,400 acre-feet per year (USGS, 1991).

L. Santa Cruz River

The Santa Cruz River is primarily an ephemeral stream which drains approximately 8,600 square miles in southern Arizona. The river flows from its headwaters southward into Mexico and loops north to re-enter the United States near Nogales. From Nogales the Santa Cruz flows north to Tucson. The river flows northwestward from Tucson through the Lower Santa Cruz, Eloy, and Maricopa-Stanfield sub-basins. The Santa Cruz enters the study area near Maricopa, and flows through the Gila Indian Reservation to Gila Crossing where it joins the Gila River.

There are several short perennial reaches along the Santa Cruz River where treated wastewater is discharged into the river channel. These reaches occur downstream from wastewater treatment plants located near Nogales, Tucson, and Casa Grande. The average annual flow of the Santa Cruz River near Laveen was approximately 17,700 acre-feet per year from 1941-1990. The median annual flow was approximately 6,200 acre-feet per year (USGS, 1991).

II. SURFACE WATER QUALITY

Although all of the rivers and streams discussed above serve as a source of groundwater recharge, only the Gila, Salt, Verde, and Agua Fria Rivers are used directly for water supply. The chemical quality of the water in these rivers is generally good within the study area. The reported values for total dissolved solids, sulfate, nitrate, and metals are all well within primary and secondary standards with the exception of the Gila River, which is characterized by sulfate values of around 500 milligrams per liter, twice the secondary maximum contaminant level of 250 milligrams per liter (ADWR, 1991). High sulfate levels in the Gila River may be caused in part by effluent discharged from the City of Phoenix wastewater treatment plants.

CHAPTER FOUR. THE PREDEVELOPMENT HYDROLOGIC SYSTEM - CIRCA 1900

I. BACKGROUND, CHARACTERISTICS, AND 1900 WATER LEVELS

The predevelopment hydrologic system of the SRV has been studied to serve as the time-frame for the steady-state calibration of the groundwater flow model. The various components of groundwater inflow and outflow have been identified and analyzed for the predevelopment hydrologic system. The components include underflow, perennial and ephemeral stream channel infiltration, mountain front recharge, and evapotranspiration. The following sections discuss the characteristics, water levels, inflows and outflows of the predevelopment hydrologic system.

Prior to the arrival of non-Indian settlers in the SRV during the 1860's and 1870's the hydrologic system was in a state of equilibrium. The long-term inflows and outflows were in balance, and water levels remained more or less constant with time (steady-state). After the Civil War many non-Indian settlers arrived in the SRV and began to divert the surface waters of the Salt and Gila Rivers. Approximately 60,000 acres were irrigated under the Arizona Canal system by 1885 (Davis, 1897).

By 1900 the over-application of agricultural irrigation water and canal seepage had caused water levels to rise above predevelopment levels in many parts of the irrigated SRV. However, Lee (1905) reported that water levels had declined prior to 1905 due to a prevailing drought and also because of the increasing number of wells in use. The configuration of the water table, circa 1900, is shown in Figure 18. The 1900 water level map was adapted mainly from the depth to water map constructed by Lee (1905), and predevelopment water level maps constructed by

Anderson (1968), Thomsen and Baldys (1985). Although the effects of irrigation seepage and drought conditions on the groundwater levels of the early 1900's are unknown, it is probable that the effects were minimal and the water levels measured by Lee (1905) adequately represent predevelopment conditions (Thomsen and Porcello, 1991). Groundwater flow in the predevelopment system is assumed to have been primarily horizontal. Vertical head differences probably occurred in zones of inflow or outflow, but these zones are not known to be extensive or mappable (Freethy and Anderson, 1986).

II. WATER BUDGET COMPONENTS OF THE PREDEVELOPMENT HYDROLOGIC SYSTEM

A. Underflow

The direction of groundwater flow can be inferred from the orientation of the predevelopment water table (Figure 18). Lee (1905) described the water table as "a comparatively regular plain, sloping in general with the grade of the river." The predevelopment water level contours indicate that groundwater underflow occurred in several locations around the periphery of the study area (Figure 18). Within the study area groundwater generally flowed from east to west. Near Tempe some underflow moved westward following the modern channel of the Salt River between the Papago Buttes and Tempe Butte. The predevelopment water level contours indicate that some of the Salt River underflow moved through the gap between Tempe Butte and the South Mountains (Lee, 1905), (Thomsen and Porcello, 1991). However, most of the underflow followed the ancient channel deposits of the Salt River and joined the underflow of the Gila River east of the South Mountains (Lee, 1905). Substantial underflow moved northwestward along the channel of the Gila River and passed through the gap between the South Mountains and the Sierra Estrella. West of the confluence of the Salt and Gila Rivers underflow generally moved to the west, with underflow also converging from the north. Groundwater underflow exited the WSRV to the southwest along the Gila River channel near Arlington. Initial estimates of predevelopment underflow were provided from flow net analysis. These estimates have been modified based on steady state modeling results (ADWR, 1992b). Predevelopment groundwater underflow entering the study area is estimated to have been approximately 32,000 acre-feet per year. The underflow exiting the study area is estimated to have been approximately 2,000 acre-feet per year (Figure 19).

B. Perennial Stream Recharge

In predevelopment times the Salt and Gila Rivers were perennial throughout the model area (Brown and others, 1977). There were several areas of groundwater recharge and groundwater discharge along the rivers during the predevelopment era (Figure 20). In general groundwater was recharged along "losing" reaches where the water table elevation was less than the water level elevation in the river channel (river stage). Losing reaches occurred near the inflow portions of the valleys where the depth to water was relatively great, and the underflow tended to diverge from the general course of the rivers. Groundwater was discharged to the rivers along "gaining" reaches where the water table elevation was greater than the river stage.

Gaining reaches typically occurred in locations where large volumes of underflow converged upon zones of reduced aquifer cross-section, such as near bedrock narrows or boundaries.

The Salt River was a losing river for about the first 10 miles downstream of the present location of Granite Reef Dam, and for about 20 miles downstream of Tempe. The Salt became a gaining river about 5 miles east of Tempe, and about 3 miles east of its confluence with the Gila River. The Gila River was a gaining river from near Coolidge to a point about 5 miles east of Sacaton. The Gila River was a losing river east of Sacaton to Pima Butte. The Gila was predominately a gaining river from Pima Butte to a location northwest of the Sierra Estrella. The Gila was nearly in equilibrium with the aquifer west of the Sierra Estrella with only minor recharge occurring to Arlington.

Initial estimates of perennial stream recharge and discharge during the predevelopment era were provided by several researchers (Code, 1901), (Lee, 1904, 1905), (Thomsen and Porcello, 1991), (Thomsen and Eychaner, 1991). The original estimates have been refined based on steady state modeling results (ADWR, 1992b). The total volume of water which was recharged by the Salt and Gila Rivers in the predevelopment era in the SRV is estimated to have been approximately 81,000 acre-feet per year. The total volume of water which was discharged by the aquifer to the Salt and Gila Rivers in the predevelopment era in the SRV is estimated to have been approximately 61,000 acre-feet per year.

C. Ephemeral Streams

Groundwater recharge also occurred along ephemeral streams during the predevelopment era (Figure 19). Original estimates of ephemeral stream channel infiltration were based on stream flow records provided by USGS stream gages. Those estimates were modified based on the results of steady state modeling (ADWR, 1992b). Predevelopment recharge from the Agua Fria River, Cave Creek, New River, Skunk Creek, and Queen Creek is estimated to have been approximately 20,000 acre-feet per year.

D. Mountain-Front Recharge

Mountain-front recharge is water that infiltrates into the zone of coarse alluvium that extends several miles basinward from the mountain-basin interface (Anderson and others, 1990). The distribution of mountain-front recharge is a function of the average precipitation in the adjacent mountain areas. The average annual precipitation is related to altitude. Mountain-front recharge, therefore, is expected to be greater in basins surrounded by the higher mountain ranges (Anderson and others, 1990).

The altitude of the mountains surrounding the SRV study area is generally low except in the ESRV where the Superstition Mountains reach an average elevation exceeding 4,000 feet. It has been assumed that mountain-front recharge was only significant in the ESRV along the McDowell and Superstition Mountains. Initial estimates of mountain-front recharge were provided by Thomsen and Porcello (1991), and were modified based on the results of steady-state modeling (ADWR, 1992b). The estimated volume of mountain-front recharge along the Superstition Mountains was approximately 6,000 acre-feet per year, and along the McDowell Mountains was approximately 1000 acre-feet per year.

E. Evapotranspiration

The major source of discharge from the predevelopment groundwater system was through evapotranspiration. Evapotranspiration is defined as "water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration" (Langbein and Iseri, 1960). Along the Salt and Gila Rivers cottonwood, seepwillow, arrowweed, and mesquite have been present for several centuries, forming open stands and clusters (Figure 21). The main channels had extensive areas of open sand, and the channels were occupied by water continuously (Graf, 1980). Initial estimates of predevelopment phreatophyte distributions were based on the modern distribution of phreatophytes, along with the distributions provided by Thomsen and Porcello (1991), and Thomsen and Eychaner (1991). The total phreatophyte acreage in the SRV study area during the predevelopment era was estimated to have been approximately 48,000 acres. The phreatophyte acreage total was multiplied by an evapotranspiration rate of 1.6 acre-feet per acre to derive a total evapotranspiration loss of approximately 76,000 acre-feet per year. The 1.6 acre-feet per acre rate was determined from a phreatophyte clearing project along the Upper Gila River (Culler, 1982).

F. Conceptual Groundwater Budget -- Circa 1900

A predevelopment groundwater budget has been developed for the SRV study area (Table 2). The total inflows and outflows were in approximate balance and are estimated to have been approximately 139,000 acre-feet per year.

Table 2
Predevelopment Groundwater Budget For SRV Study Area
(Figures Rounded to Nearest 1000 Acre-Feet)

INFLOW	***AF/YR***
Perennial Stream Channel Recharge	81,000
Underflow	31,000
Ephemeral Stream Channel Recharge	20,000
Mountain Front Recharge	7,000
Total Inflow	139,000
OUTFLOW	***AF/YR***
Perennial Stream Channel Discharge	61,000
Evapotranspiration	76,000
Underflow	2,000
Total Outflow	139,000

CHAPTER FIVE. THE MODERN HYDROLOGIC SYSTEM -- 1978-1988

I. BACKGROUND, CHARACTERISTICS, AND 1983 WATER LEVELS

The modern hydrologic system of the SRV (1978 to 1988) has been studied to serve as the time-frame for the transient-state calibration of the groundwater flow model. The various components of ground water inflow and outflow have been identified and analyzed for the modern hydrologic system. The components include underflow, multiple sources of recharge, pumpage, and evapotranspiration. The following sections discuss the characteristics, water levels, inflows and outflows of the modern hydrologic system.

The modern hydrologic flow system in the SRV has been shaped by the activities of man. The system is dominated by regional pumping centers, and recharge supplied mainly from agricultural recharge, canals, and occasional flood events. It is a dynamic system which responds to the stresses of pumpage and recharge by adjusting the volume of groundwater in storage. Since 1900 groundwater overdraft has reduced the volume of groundwater in storage by approximately 23 million acre-feet, and has caused large declines in the water table in most areas. Various trends in water level change are shown in numerous hydrographs which are located in Appendix II of this report.

Today's groundwater flow system is exceedingly complex. The UAU has been substantially dewatered in many areas, and vertical hydraulic gradients have developed in many locations. Vertical hydraulic head differences exceeding 100 feet have been measured between the UAU and LAU in the Scottsdale area where significant dewatering of the UAU has occurred, and groundwater is pumped from the lower fine-grained sediments of the MAU, LAU, and Red Unit (ADWR, 1990). The vertical gradient has developed in this area as the hydraulic head in the lower fine-grained sediments has been reduced due to pumpage. The head has not equilibrated vertically through the aquifer due to the low hydraulic conductivity of the intervening fine-grained sediments. For this reason a long-term vertical flow regime has been established. Vertical gradients in most other parts of the study area are not well known, but have been estimated from 1983 unit-specific and composite water level data. Unit-specific water level maps based on GWSI water levels measured between July of 1982 and June of 1983 have been produced for the UAU and the MAU (Plates 1 and 2). Available data indicate MAU and LAU water levels for 1983 were essentially the same, except in the Scottsdale, Chandler Heights, Deer Valley, and Litchfield Park areas where MAU water levels ranged from 20 to 40 feet higher than LAU water levels.

II. WATER BUDGET COMPONENTS OF THE MODERN HYDROLOGIC SYSTEM

A. Underflow

In the ESRV groundwater flow is directed toward three regional pumping centers (Plate 2). In the east Mesa and Gilbert areas (Townships 1 North and 1 South, Ranges 6,7 East) groundwater flow is directed toward a large elongated north-south trending groundwater depression which is bounded to the northeast by the Usery Mountains and Goldfield Mountains. In the Queen Creek and Chandler Heights area (Township 2 South, Ranges 7,8 East) groundwater flow is directed toward another large groundwater depression which is bounded to the south by the Santan Mountains (Plate 2). Both the East Mesa and Chandler Heights depressions result from long-term overdraft of the groundwater aquifer by agricultural irrigation. Groundwater flow is also directed toward a groundwater depression in the northwest Scottsdale and Paradise Valley areas (Township 4 East, Ranges 2,3 North) (Plate 2). This depression is bounded to the west by the Papago Buttes, Camelback Mountain, and Mummy Mountain. The depression has been caused by long-term municipal and urban irrigation pumpage.

The direction of groundwater underflow has also changed since the predevelopment era in the central and southern parts of the study area. During the predevelopment era groundwater flowed in response to the regional gradient generally from east to west along the modern and ancestral channels of the Salt River. Today a groundwater divide has formed in the East Phoenix and Tempe area (Plate 1). The divide has formed in response to long-term regional pumping in the ESRV and WSRV sub-basins, and its presence indicates that the sub-basins are essentially hydraulically isolated in that area. In the Maricopa area (Township 4 South, Ranges 3,4 East) groundwater now flows southward toward a major agricultural pumping center located in the Maricopa-Stanfield sub-basin.

In the WSRV groundwater also flows toward areas of intense regional pumpage (Plate 2). A large groundwater depression caused by agricultural pumpage has formed in the Deer Valley area north of Glendale (Township 4 North, Ranges 1,2 East). The depression is bounded to the north and east by the Hedgpeth Hills and the Union Hills. Long-term agricultural pumpage in the Goodyear and Litchfield Park area (Townships 2,3 North, Ranges 1,2 West) has lowered water levels by over 200 feet in an area covering over 100 square miles. The groundwater depression which has formed is bounded to the west by the White Tank Mountains, and to the south by a groundwater divide from which underflow diverges northward toward the Goodyear-Litchfield Park area, and southwestward toward the channel of the Gila River in the Buckeye area. Groundwater levels are extremely shallow in the Buckeye area due to fact that there is abundant recharge from agricultural irrigation and canal seepage, and also because all surface and subsurface flows in the entire SRV, not otherwise diverted, exit the valley through this constricted, topographically low-lying area. Figure 22 shows areas of underflow around the periphery of the SRV study area for period 1978 through 1988. Estimates of underflow were provided from flownet analysis and from transient modeling results (ADWR, 1992b). The total estimated underflow entering the study area for the 1978-1988 period was approximately 24,000 acre-feet per year. The total estimated underflow exiting the study area for the 1978-1988 period was 30,000 acre-feet per year.

B. Groundwater Recharge

1) Maximum Potential Recharge Estimates

Recharge represents the major inflow to the modern groundwater system. Sources of groundwater recharge within the study area were identified and the maximum potential recharge from each source was quantified. The maximum potential recharge for each recharge source was calculated to provide a high-end estimate for the potential range of recharge. The maximum potential recharge values presented in this report served as initial transient model inputs. The sources identified include incidental recharge from agricultural and urban irrigation, seepage from canals, artificial lakes, treated effluent discharged into river channels, and naturally occurring recharge from flood flows along the major drainages and mountain fronts within the SRV.

The maximum potential recharge for 1978 through 1988 for all sources is listed in Table 3. It should be noted that the period 1978 to 1988 was wetter than most other decades of this century, and therefore, the recharge estimates derived for this period may be significantly higher than the long-term averages. Methodologies used to estimate the maximum potential recharge from each source are summarized and discussed below. The methodologies were either adopted from previous work or developed by the ADWR.

Table 3
Estimated Maximum Potential Recharge From All Sources Within The SRV Study Area
1978-1988
(Figures rounded to nearest 1000 Acre-Feet)

Year	*Agriculture Recharge*	*Urban Irrigation Recharge*	*Canal Recharge*	*Artificial Lake Recharge*	*Effluent Recharge*	*Major Drainage Recharge*	*Mountain Front Recharge*	*Ephemeral Stream*	*Annual Total*
1978	672,000	58,000	241,000	7,000	40,000	495,000	7,000	9,000	1,529,000
1979	688,000	58,000	263,000	7,000	45,000	636,000	7,000	9,000	1,713,000
1980	706,000	58,000	256,000	7,000	47,000	774,000	7,000	9,000	1,864,000
1981	726,000	58,000	300,000	7,000	49,000	3,000	7,000	9,000	1,159,000
1982	581,000	58,000	245,000	7,000	43,000	48,000	7,000	9,000	998,000
1983	441,000	58,000	200,000	7,000	34,000	776,000	7,000	9,000	1,532,000
1984	561,000	58,000	207,000	11,000	26,000	161,000	7,000	9,000	1,040,000
1985	464,000	58,000	213,000	13,000	24,000	317,000	7,000	9,000	1,105,000
1986	415,000	58,000	184,000	13,000	40,000	29,000	7,000	9,000	755,000
1987	450,000	58,000	172,000	13,000	45,000	31,000	7,000	9,000	785,000
1988	495,000	58,000	157,000	13,000	46,000	22,000	7,000	9,000	807,000
Total	6,199,000	638,000	2,438,000	105,000	439,000	3,292,000	77,000	99,000	13,287,000

2) Agricultural Irrigation Recharge

The methodologies used to calculate the maximum potential recharge from agricultural irrigation were developed utilizing cropped acreage summaries, water use data, irrigation efficiency data, and cropped acreage distributions determined from the interpretation of aerial photographs and LandSat digital images. The estimated maximum potential recharge from agricultural irrigation ranged from 672,000 acre-feet per year in 1978 to 495,000 acre-feet per year in 1988. The 1978-1988 total estimated recharge from agricultural irrigation was 6,199,000 acre-feet (Table 4).

1978-1988 Recharge Estimates

The maximum potential recharge from agricultural irrigation was estimated using a three-step process. The first step consisted of estimating the annual cropped acreage in the study area from 1978 to 1988. This was accomplished by tabulating acreage totals for all major crops grown in Maricopa County during that time period (Arizona Agricultural Statistics, 1981, 1984, 1987, 1991). The Maricopa County totals were multiplied by 82 percent to account for acreage which was inside the county, but outside the study area (Table 4).

The next step consisted of estimating annual water use by crop. This was accomplished by multiplying the individual crop acreage totals by appropriate consumptive use factors, and dividing the calculated volume by an estimated average irrigation efficiency of 65 percent.

Individual Crop Water Use = (Ind. Crop Acreage * Consumptive Use)/Estimated Average Irrigation Efficiency

Table 4
Estimated Cropped Acreage, Water Use, And Maximum Potential Recharge From Agricultural Irrigation In Maricopa County And The SRV Study Area 1978-1988

	1978	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*
AG Acreage in Maricopa County (Acres) (1),(2)	414,000	425,000	461,000	486,000	362,000	275,000	356,000	289,000	253,000	276,000	305,000
AG Acreage in SRV Model Area (Acres) (3)	339,000	348,000	378,000	399,000	297,000	226,000	292,000	237,000	207,000	226,000	250,000
AG Water Use in Maricopa County (AF/YR) (1),(4)	2,340,000	2,397,000	2,458,000	2,528,000	2,023,000	1,536,000	1,956,000	1,617,000	1,448,000	1,570,000	1,725,000
AG Water Use in SRV Model Area (AF/YR)	1,919,000	1,966,000	2,016,000	2,073,000	1,659,000	1,260,000	1,604,000	1,326,000	1,187,000	1,287,000	1,415,000
Max. Pot. Recharge in Maricopa County (AF/YR) (1),(5)	819,000	839,000	860,000	885,000	708,000	538,000	685,000	566,000	507,000	550,000	604,000
Max. Pot. Recharge in Model Area (AF/YR)	672,000	688,000	706,000	726,000	581,000	441,000	561,000	464,000	415,000	450,000	495,000
Estimated Totals:											
Agricultural Water Use in Maricopa County 1978-1988 (Ac-Ft)											21,598,000
Agricultural Water Use in SRV Study Area 1978-1988 (Ac-Ft)											17,712,000
Maximum Potential Recharge from Agriculture Irrigation in Maricopa County 1978-1988 (Ac-Ft)											7,561,000
Maximum Potential Recharge from Agriculture Irrigation in SRV Study Area 1978-1988 (Ac-Ft)											6,199,000

Notes:

1) Acreage figures rounded to the nearest 1,000 acres. Water use and recharge figures rounded to nearest 1,000 acre-feet.
2) Ag acreage in Maricopa County from Arizona Agricultural Statistics Reports (1981, 1984, 1987, 1991).
3) Ag acreage in SRV study area estimated to be approximately 82 percent of Maricopa County total.
4) Ag water use is the sum of individual crop water use totals. These totals were estimated based upon annual individual crop acreage totals, consumptive use factors, and an average irrigation efficiency of 65 percent.
5) Maximum potential recharge equals (1-irrigation efficiency) * Ag water use.

The total annual agricultural water use in the study area was estimated by summing the individual crop estimates. The consumptive use factors applied are listed in the Phoenix AMA Second Management Plan Report (ADWR, 1991). The average irrigation efficiency of 65 percent was estimated as a weighted average proportional to the existing acreage and irrigation efficiencies of various types of irrigation systems within the Phoenix AMA (ADWR, 1991).

The maximum potential recharge from agricultural irrigation was calculated by multiplying the total agricultural water use in the study area by the estimated irrigation inefficiency (1- irrigation efficiency).

$$\text{Annual Maximum Potential Recharge} = (\text{Annual Agricultural Water Use})\ (1\text{-Irrigation Efficiency})$$

The estimated recharge totals are listed in Table 4.

Recharge Distribution

The estimated distribution of agricultural recharge was based upon three factors: 1) the regional distribution of reported water use, 2) irrigation efficiencies, and 3) the local distribution of cropped acreage. The regional distribution of water use was estimated from data reported by individual irrigation grandfathered rightholders (IGFRs). This data was tabulated from the ADWR-ROGR database into water use by irrigation district totals. For convenience, water use totals were summed for certain irrigation districts which are designated as being within Areas of Similar Farming Conditions (ASFCs) (ADWR, 1987). An ASFC typically corresponds to one or more irrigation districts which have similar farming practices, land conditions, and economic characteristics. There are 8 major ASFCs within the SRV study area (Figure 23). Water use was estimated for Indian communities based upon reported cropped acreage, and assumed consumptive use and irrigation efficiencies. The regional distribution of water use is summarized in Table 5.

It should be noted that the regional distribution of agricultural water use was estimated only for the years 1987 and 1988. It would have been desirable to determine the distribution for earlier years. However, ROGR database limitations do not permit the tabulation of individual irrigation district water use totals for years prior to 1987. It has been assumed for modeling purposes that the 1987-1988 average regional distribution of water use was generally representative of earlier years.

The annual recharge totals were apportioned to each ASFC and Indian community as a weighted average proportional to annual water use and average irrigation efficiency. Average irrigation efficiencies were calculated as weighted averages proportional to the existing acreage and irrigation efficiencies of a representative sample of farms within each ASFC (ADWR, 1987). Indian irrigation efficiencies were estimated.

Recharge was apportioned locally within each ASFC and Indian community based upon the cropped acreage distribution. The distribution of cropped acreage was estimated through analysis of aerial photographs and LandSat digital images. Two different years, 1979 and 1987, were selected to estimate the historical change in cropped acreage. The 1979 distribution of cropped acreage was based on the interpretation of aerial photographs. The 1987 distribution of cropped acreage was based on interpretation of LandSat digital images. An average of 1979 and

Table 5
Analysis Of Irrigation Efficiencies, Water Use, And Recharge Percentages For Major Agricultural Water Users In The SRV Study Area (1987-1988)

(Water Use and Recharge Figures Rounded to Nearest 100 Acre-Feet)

ASFC No.	*Major Irrigation Districts and Indian Communities*	*Average Irrigation Efficiency (1)*	*1987-1988 Average Water Use (2)*	*Percentage of Total Annual Ag Water Use*	*Percentage of Total Annual Ag Recharge (3)*
3	Roosevelt I.D.	0.59	168400	12%	13%
4	Buckeye I.D. St. Johns I.D. Arlington I.D.	0.71	99400 10000 24300	10%	7%
5	Adaman I.D. Maricopa W.C.D. #1	0.56	5600 72100	6%	6%
8	Salt River Project Peninsula Ditch Co.	0.62	358000 11300	27%	27%
9	Roosevelt W.C.D.	0.64	127600	9%	9%
10	New Magma I.D.D. Queen Creek I.D. San Tan I.D. Chandler Heights I.D.	0.58	63000 35500 8700 4600	8%	9%
(4)	Small Irrigation District IGFR	0.60	8700	<1%	1%
(4)	Non-Irrigation District IGFR	0.60	136700	10%	10%
(4)	Salt River Pima Indian Community	0.60	37800	3%	3%
(4)	Gila River Indian Community	0.60	200400	15%	15%
Totals			**1372200**	**100%**	**100%**

Notes:

1) Average irrigation efficiencies are a weighted average proportional to the existing acreage and efficiencies of various types of irrigation systems within each ASFC (ADWR, 1987). Small district, non-district and Indian irrigation efficiencies are estimated.
2) Average 1987-1988 water use for irrigation districts and non-irrigation district IGFRs is reported data from ADWR-ROGR database. Indian water use is estimated based upon BIA reported cropped acreage totals, and assumed consumptive use and irrigation efficiency data (U.S. Bureau of Indian Affairs, 1978-1988).
3) Percentage of total annual Ag recharge is a weighted average proportional to (1-Irrigation Efficiency) and the annual water use of each major water use entity in the study area.
4) Not Applicable.

1987 cropped acreage was calculated for each section in the study area. The annual recharge totals for each ASFC and Indian community were distributed in proportion to the 1979-1987 average acreage distribution. The estimated average maximum potential recharge distribution for the period 1978-1988 is shown in Figure 24.

3) Urban Irrigation Recharge

The maximum potential recharge from urban irrigation was divided into two categories: turfed areas less than 10 acres and turfed areas greater than 10 acres. Turfed areas less than 10 acres include residential homes, small parks, and churches. Turfed areas greater than 10 acres include golf courses, cemeteries, schools, and large parks. Data for estimating recharge from turfed areas less than 10 acres were provided by the Salt River Project for their service area. Data for estimating recharge from turfed areas greater than 10 acres were provided by the Phoenix AMA. The total maximum potential recharge from all turfed areas within the Salt River Valley was estimated at approximately 58,000 AF/YR.

The methodology used to estimate recharge from both categories of urban irrigation consisted of identifying the total turfed acreage and volume of water applied per square mile and deriving a total consumptive use assuming all turfed areas are 100 percent bermuda grass. The consumptive use of bermuda grass was assumed to be 3.63 AF/AC/YR (U.S. Department of Agriculture, 1982). The maximum potential recharge per section was estimated by subtracting the total consumptive use requirement from the total water applied.

Recharge from turfed areas greater than 10 acres was estimated within the SRV for 1987. The areal location, total turfed acreage, and volume of water applied were provided by the Phoenix AMA. The maximum potential recharge was estimated at approximately 24,600 AF/YR. There were 339 facilities identified within the SRV with turfed areas greater than 10 acres.

Recharge from turfed areas less than 10 acres was estimated within the Salt River Project (SRP) service area for 1988. Limited data prevented a historical analysis of recharge. The SRP provided the total gross acreage per section for individual turfed areas less than 10 acres that obtain water for flood irrigation. The total gross acreage for 1988 within the SRP service area is 25,950 acres and total water delivered was 94,040 AF.

The total gross acreage is not necessarily the actual turfed area. Only a percentage of the total acreage of each account is actually covered with turf. The gross acreage was reduced to the actual irrigated acreage using two factors. Based upon a sampling of different types of turfed areas less than 10 acres, the percentage of each account assumed to be covered with turf was 65 percent, and the other 35 percent was assumed to be covered with buildings, driveways, or parking lots. Approximately 5,700 net acres were identified to have insufficient water applied to satisfy the consumptive use requirement for bermuda grass. These areas were assumed to not contribute to ground water recharge. Several factors may be attributed to why some areas had an insufficient volume of water applied. These include: 1) these turfed areas may have received water from a source other than SRP (for example, rainfall, private wells); 2) these areas may have been underwatered; 3) or the assumption that all turfed areas are 100 percent bermuda grass may not be valid (that is, the total consumptive use requirement is too high).

Approximately 13,200 net acres were identified to have excess water applied above the consumptive use requirement for bermuda grass. The total water applied to these acres was estimated at 81,600 acre-feet. The maximum potential recharge from excess urban irrigation applied to was estimated at 33,700 acre-feet. This was estimated by calculating the consumptive use requirement of the total net turfed acres and subtracting that quantity from the total water applied. For example; 81,600 AF – (13,200 AC * 3.63 AF/AC/Yr) = 33,700 acre-feet, or 2.6 acre-feet per acre of recharge.

4) Canal Recharge

Seepage rates were estimated from the main canals of the seven major irrigation districts within the SRV. These include canals from the Salt River Project (SRP), Central Arizona Project (CAP), Buckeye Irrigation Company (BIC), Roosevelt Irrigation District (RID), Maricopa Water District No. 1 (MWD), Roosevelt Water Conservation District (RWCD), and the San Carlos Irrigation Project (SCIP) (Figure 25). Data were obtained from each irrigation district or by field inspection if no data were provided. Data requested included canal lining and construction details, survey data for canal dimensions, canal-specific infiltration tests, water level information (for example, forebay or high water level mark) and length of time the canals are full.

The general methodology used to estimate seepage volumes, data permitting, was to calculate a wetted canal area per section and assume an infiltration rate per square-foot of wetted area. Infiltration rates were either provided specifically for each canal by the irrigation districts (for example, BIC and CAP) or obtained from other sources depending upon whether the canal was lined or unlined.

The total volume of water recharged from canals within the model domain was estimated at approximately 2.4 million acre-feet between 1978-1988. Table 6 presents the total volume of recharge estimated from each irrigation district's canals. The specific methodology for estimating recharge from each irrigation district is discussed below.

Table 6
Estimated Maximum Potential Recharge From Canal Infiltration In The SRV Study Area 1978-1988
(x1000 Acre-Feet/Year)

	Salt River Project		Central Arizona Project		Buckeye Irrigation Company		Roosevelt Irrigation District		Roosevelt Water Conservation District		Maricopa Water District No. 1		San Carlos Irrigation Project	
Year	D	R	D	R	D	R	D	R	D	R	D	R	D	R
1978	1,051	104			132	32	95	*37	105	1		11	117	56
1979	1,338	104			134	32	108	37	125	1		11	171	78
1980	1,446	*81			165	32	122	37	135	1		11	202	94
1981	1,222	81			199	32	124	37	147	1		11	230	138
1982	1,054	*72			185	32	104	37	117	1	No	11	169	92
1983	1,171	72			141	32	82	37	98	1	Data	11	116	47
1984	1,008	72			200	32	105	37	116	1	Available	11	175	54
1985	1,136	*54	34		189	32	117	37	119	1		11	198	78
1986	994	54	109	*17	204	32	118	*3	115	1		11	189	66
1987	1,095	54	355	17	209	*32	120	3	127	1		11	205	54
1988	1,054	*34	499	17	203	32	124	3	133	*1		*11	216	59
Total	12,569	782	997	51	1,961	352	1,221	305	1,339	11		121	1,988	816
Percent	6%		5%		18%		25%		<1%				41%	

Estimated Maximum Potential Recharge 1978-1988: 2,438,000 acre-feet

Notes: D = Diverted R = Recharge * Denotes year infiltration volume was estimated. Value assumed constant until the next year calculated.
- Diverted values include total surface water and ground water transmitted through canal system (generally greater than the total water delivered to farms); values rounded to nearest 10 acre-feet.
- All recharge estimates rounded to nearest 1000 acre-feet.
- Percentage of estimated canal seepage versus total water transmitted through the canal system for 11 years.

Sources:
- Salt River Project: Operation and Statistics Report, 1987 & 1988; provided by SRP.
- Central Arizona Project: Diverted from Lake Havasu, Gage #09426650; provided by USGS.
- Buckeye Irrigation Company: Total surface water diverted at the Buckeye Heading; provided by BIC
- Roosevelt Irrigation District: Total groundwater transmitted through canal system; provided by RID.
- Roosevelt Water Conservation District: Total surface water diverted from Southern Canal and groundwater pumped; provided by RWCD.
- Maricopa Water District No. 1: No data provided.
- San Carlos Irrigation Project: San Carlos Irrigation Project Annual Reports 1978-1988. Water delivery data.

Salt River Project Canal Recharge

The maximum potential recharge from SRP canals and major laterals was estimated, by determining the wetted area per section of each canal and multiplying by a representative infiltration rate. Canal recharge was estimated for five separate years: 1977, 1980, 1982, 1985, and 1988. The years correspond with the publication of the Water Transmission System Booklets (SRP, 1989a). The total volume of recharge between 1978 and 1988 was estimated at 782,000 acre-feet. Table 7 presents the annual volume of recharge estimated from each canal and major lateral.

Wetted perimeters for each canal and major laterals were estimated by obtaining canal survey and forebay elevation data from SRP at selected locations (that is, control points). A total of 22 survey points at 20 separate locations were obtained. The number of survey and forebay elevation locations for each canal and major laterals varied. The survey data collected for each canal and major laterals were used to construct cross-sections.

The wetted perimeter for each canal and major lateral was estimated using the annual average forebay elevation (water level elevation) at each control point. This calculation takes into account the seasonal water level fluctuation between summer and winter. However, no forebay data were provided for major laterals. The high water mark was used to estimate the wetted perimeter for each major lateral. The wetted perimeter calculated at each control point was assumed constant downstream to the next control point.

Table 7
Estimated Maximum Potential Recharge For Selected Years From SRP Canal System
(Figures Rounded to Nearest 100 Acre-Feet/Year)

CANALS	*1977*	*1980*	*1982*	*1985*	*1988*
Arizona	42,700	27,400	24,800	15,400	8,700
Grand	22,300	20,300	19,100	17,000	9,500
Southern	1,400	1,400	1,400	1,400	1,400
Eastern	2,300	900	900	900	900
Consolidated	13,900	13,700	11,800	7,500	4,600
Tempe	7,700	4,100	2,500	1,200	1,200
Western	7,600	6,900	5,800	4,100	1,800
Major Laterals					
Highline	1,500	1,500	1,500	1,500	1,500
Kyrene	500	500	500	500	500
Lateral 1-20.0	1,400	1,400	1,400	1,400	1,400
Lateral 2-23.0	1,000	1,000	1,000	1,000	1,000
Lateral 5-9.5	1,700	1,700	1,700	1,700	1,700
Total	104,000	80,800	72,400	53,600	34,200

Small Laterals:
Urban Areas Infiltration volume = 50 acre-feet/square-mile/year
Agricultural Areas Infiltration volume = 130 acre-feet/ square-mile/year

Notes: Assumptions for Calculation of Infiltration Volumes

- 11 months per year is the assumed period canals are full of water.
- Canal width constant between survey control points.
- Canal width constant through time.
- Each lined or unlined portion was assumed to be totally lined or unlined throughout the entire square mile.

For example, if a canal was lined less than 50 per cent within a given square mile (that is, only a small portion was lined), it was assumed to be completely unlined within the section, and visa versa.

- Infiltration rates are representative of actual canal hydraulic conditions - construction of major laterals were assumed to be lined with concrete in fair condition.
- Historical major lateral construction data were not available, therefore, infiltration volumes were assumed constant through time.

Wetted areas for each canal and major lateral were estimated by multiplying the length of canal per section by the estimated wetted perimeter. The length of each canal per section was calculated using the Water Transmission System Booklet (SRP, 1989a). The booklets delineate, in detail, the length of canal and status of canal lining per square-mile (i.e., lined or unlined).

Infiltration rates for either the lined or unlined portion of the canals and major laterals were obtained from the USBR or SRP. Seepage tests conducted on the Tucson Aqueduct portion of the CAP canal were used as representative of a concrete lined canal infiltration rate (USBR, 1989a). Estimated infiltration rates for the unlined portion of the canals were provided by SRP in a memo to ADWR (SRP, 1990a). Table 8 presents the infiltration rates used for estimating infiltration volumes.

Table 8
Infiltration Rates Used For Estimating Recharge From Lined Or Unlined Canals

LINED CANALS AND MAJOR LATERALS	
Concrete in Good Condition: 0.05 CuFt/SqFt/Day (USBR, 1990a)	
Concrete in Fair Condition: 0.24 CuFt/SqFt/Day (USGS, 1980)	
UNLINED CANALS AND MAJOR LATERALS ***Salt River Project (SRP, 1990a)***	
1977 = 0.52 CuFt/SqFt/Day	1980 = 0.47 CuFt/SqFt/Day
1982 = 0.44 CuFt/SqFt/Day	1985 = 0.39 CuFt/SqFt/Day
1988 = 0.25 CuFt/SqFt/Day	

Note: The declining system-wide infiltration rates provided by SRP for unlined canals and major laterals reflects the progressive lining of the canal system to eliminate the worst seepage losses each year. However, these estimates are subjective and are not supported by field test data.

The estimated annual canal recharge per section was calculated by multiplying the wetted area per section by the infiltration rate. Eleven months was selected as the annual period when the SRP canal system is full of water. The recharge volume per section was assumed constant unless additional data was available. For example, the total recharge for 1977 was estimated to be 104,000 acre-feet, and this volume was assumed constant for 1978 and 1979.

Central Arizona Project Canal Recharge

The maximum potential recharge from the Central Arizona Project (CAP) canal seepage was estimated by calculating the wetted area per section and multiplying by a representative infiltration rate. The CAP aqueduct began delivering water to the Phoenix area in November, 1985. Therefore, canal seepage was estimated for the three year period between 1986 and 1988. The total volume of recharge for the period 1986 to 1988 was estimated at approximately 51,000 acre-feet or 16,700 acre-feet/year (Table 6).

Canal construction data were provided by the USBR. These data included wetted perimeter, aqueduct capacity, and results of a seepage test conducted on the Tucson Aqueduct portion of the CAP (U.S. Bureau of Reclamation, 1989a). The canal has four size reductions within the SRV model domain from its original 3000 Cubic Feet per Second (CFS) design capacity.

The wetted area per section was calculated by multiplying the wetted perimeter by the length of canal per section. The estimated annual recharge (infiltration volume) per section was calculated by multiplying the wetted area per section by the infiltration rate. The CAP was assumed to be full year round. The recharge volume per section was assumed constant from 1986 through 1988.

Buckeye Irrigation Company Canal Recharge

The maximum potential recharge from the unlined Buckeye Irrigation Company (BIC) canals was estimated using canal-specific infiltration rates from tests conducted by the Desert Agricultural and Technology Systems, Inc. (DATS) in 1987. These tests were conducted along various reaches of the canal system. The annual volume of recharge was estimated at approximately 32,000 acre-feet per year, or approximately 356,000 acre-feet between 1978 and 1988, assuming the infiltration rates are constant through time (Table 9).

The seepage rates for the BIC Main and South Extension canals ranged from 0.2 - 3.3 CFS/Mile (DATS, 1987). Recharge from the main canal was estimated at approximately 29,600 AF/Year and the south extension at 2,800 acre-feet/year (Table 9).

Table 9
Estimated Maximum Potential Recharge From The Buckeye Irrigation Company Canals - 1987

Main Canal	29,600 acre-feet/year
South Extension	2,800 acre-feet/year
Total	32,400 acre-feet/year
1978-1988	356,400 acre-feet

Assumptions:
- Seepage rates are representative of actual canal hydraulic conditions
- Seepage rates are constant between each test location
- Seepage rates are constant through time

Notes:
- Seepage rates were adopted from DATS (1987). Refer to DATS (1987) for a complete description of the methodology.

The estimated annual recharge per section was calculated by multiplying the calculated seepage rate by the length of canal within each section. The BIC canals were assumed to be full 11 months of the year. A map was provided by Buckeye Irrigation Company which delineated the canal length per section. Seepage rates were assumed constant downstream to the next infiltration test location. The recharge volume per section was assumed constant throughout the entire study period.

Roosevelt Irrigation District Canal Recharge

The maximum potential recharge from the Roosevelt Irrigation District (RID) canals was estimated using two separate methodologies. Volumetric flow measurements conducted in 1977 (Beck and Associates, 1984) were used to estimate recharge from 1978 through 1985. From 1986 to 1988, recharge was estimated by determining the canal wetted area per section and multiplying by a representative infiltration rate. This second methodology was used since the main canal was relined in 1986 (RID, 1989). The volumetric flow measurements estimated recharge at approximately 37,000 acre-feet per year and the wetted area measurements estimated recharge at 2,500 acre-feet per year. Table 10 presents the total recharge estimates.

Beck and Associates (1984) state that the volumetric flow measurement tests conducted in 1977 indicate that approximately 51 percent of the seepage loss is along the main canal and 28 percent is on the CC1 canal (Table 10). The remaining 21 percent seepage loss was attributed along the CC2 and Salt Canals. However, these losses were not accounted for due to the limited

Table 10
Estimated Maximum Potential Recharge From The Roosevelt Irrigation District Canals 1977 And 1986
(Figures Rounded to Nearest 100 Acre-Feet)

	Method of Recharge and Estimation	
RID Canals	***1977 Volumetric (1)***	***1986 Wetted Area (2)***
Main Canal	18,900	1,900
CC1 Canal	10,300	600
CC2 Canal	2,100	---
Salt Canal	3,300	---
Collection Canals	2,000	---
Total	36,600	2,500
Total 1978-1988	~304,000 (3)	

Notes:

1) Estimates of recharge using volumetric records from the RID canal system were distributed according to the relative distribution of seepage derived during the flow measurements conducted in August, 1977. Recharge estimates from CC2, Salt and Collection canals were not included into the model. There were not sufficient data provided to delineate their location and construction status.

2) Estimates of recharge using the wetted area methodology from the Main and CC1 canals. Construction data on these portions of the canals were obtained from Beck and Associates (1984). However, no data were provided for the CC2, Salt, and Collection Canals.

3) Assuming seepage rates and their distribution are constant through time. Assuming seepage rates are representative of actual canal hydraulic conditions. Not including seepage from CC2, Salt, and Collection canals.

information available regarding the delineation and location of the canals and construction information.

Recharge per section was estimated in two ways depending upon the method of recharge calculation (such as, volumetric or wetted area). Recharge estimated by the volumetric method was distributed evenly by dividing the total seepage loss as a weighted function of the lineal length of canal per section. For example, the annual main canal seepage loss was estimated at 18,900 acre-feet and the canal is approximately 89,550 feet in length (Beck and Associates, 1984). Therefore, the recharge was distributed at 0.21 AF/YR/lineal foot of canal (Table 10). This recharge estimate was assumed constant between 1978 and 1985.

Recharge estimated by the wetted area method was distributed by determining the wetted area of canal per section and multiplying by a representative infiltration rate. It was assumed that the RID canal was relined with concrete in good condition. The infiltration rate of 0.05 CuFt/SqFt/Day was adopted from the USBR (1989a). The recharge volume per section was assumed constant between 1986 and 1988. The length of canal per section was determined using maps provided by the RID and USGS topographic maps.

Maricopa Water District #1 Canal Recharge

The maximum potential recharge from Maricopa Water District's (MWD) Beardsley Canal was estimated by calculating the wetted area of canal per section and multiplying by a representative infiltration rate. The MWD provided no canal construction data or the total volume of water transmitted through the Beardsley canal. The total volume of recharge between

1978 and 1988 was estimated at approximately 121,000 acre-feet or 11,000 acre-feet per year (Table 6).

ADWR conducted a field trip to check the Beardsley canal construction and lining status. Where possible, the canal was checked at one or two mile intervals from near Waddell Dam to Indian School Road. The wetted perimeter of the canal was estimated using the construction data collected in the field (bottom width, high water mark width and depth). The wetted area was estimated by multiplying the wetted perimeter by the length of canal per section. The length of canal per section was estimated using USGS topographic maps.

The infiltration rate used to calculate recharge volumes was 0.24 CuFt/SqFt/Day (USGS, 1980). This rate assumes the canal is lined with concrete in fair condition. The estimated annual recharge per section was calculated by multiplying the wetted area per section by the infiltration rate. The calculation assumes that water is in the canal 11 months of the year at high water mark. This recharge volume was assumed constant from year to year since no historical canal data were provided.

Roosevelt Water Conservation District Canal Recharge

The maximum potential recharge from the Roosevelt Water Conservation District (RWCD) main canal was estimated by calculating the wetted area of canal per section and multiplying by a representative infiltration rate. The canal was assumed to be lined with concrete in good condition. The total volume of recharge between 1978 and 1988 was estimated at approximately 11,000 acre-feet or 1,000 acre-feet per year (Table 6).

The wetted perimeter of the canal was estimated by using construction information provided by the RWCD. The wetted area for the canal was estimated by multiplying the length of canal per section by the estimated wetted perimeter. The lineal length of canal per section was estimated using USGS topographic maps.

The infiltration rate for the main canal is 0.05 CuFt/SqFt/Day (USBR, 1989a). This rate assumes that the canal is lined with concrete in good condition.

The estimated annual recharge per section was calculated by multiplying the wetted area per section by the infiltration rate. The recharge volume estimated is less than one percent of the total annual volume of water transmitted through the canal system. This recharge volume is probably too low when comparing to other canal systems within the SRV. However, in the absence of canal-specific infiltration rates and historical conditions of the concrete liner, these recharge volumes were assumed constant from year to year.

San Carlos Irrigation Project Canal Recharge

The maximum potential recharge from the mainly unlined San Carlos Irrigation Project (SCIP) canal system was estimated based upon water delivery data supplied from SCIP annual reports (SCIP, 1978-1988). The reports divide water deliveries into the Indian and District "parts" of the project. The deliveries are further sub-divided into deliveries made to Indian and District "lands". It has been estimated that the study area covers approximately 85 percent of the Project's Indian Lands. No district land lies within the study area. The maximum potential recharge from SCIP canal seepage in the SRV study area was estimated as being equal to 85 percent of the difference between the deliveries to the Indian part and the Indian lands.

Several major canals or laterals deliver water to the SCIP Indian lands within the study area. The canals are: 1) the Pima Lateral, 2) the Southside Canal, 3) the Casa Blanca Canal, 4) the Old San Tan Canal, and 5) the San Tan Canal. Annual recharge estimates were apportioned to each canal based upon the average wetted perimeter, and total canal length (Table 11). Recharge was areally distributed along each canal in proportion to the length of canal per section.

Table 11
Estimated Maximum Potential Recharge From San Carlos Irrigation Project Canals In The SRV Study Area 1978-1988
(Figures Rounded to Nearest 100 Acre-Feet)

Canal	*1978*	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*
Pima Lateral	6700	9500	11300	16600	11100	5600	6400	9400	8000	6500	7100
Southside	11500	16200	19400	28400	19000	9600	11000	16100	13600	11100	12200
Casa Blanca	14000	19700	23500	34400	23000	11600	13400	19500	16600	13500	14900
Old San Tan	12500	17600	21000	30700	20500	10400	11900	17400	14800	12000	13200
San Tan	11300	15000	19000	27900	18600	9400	10800	15800	13400	10900	12000
Total	56,000	78,000	94,200	138,000	92,200	46,600	53,500	78,200	66,400	54,000	59,400

Notes:

Recharge based on water delivery data from San Carlos Irrigation Project Annual Reports (SCIP, 1978-1988). The SCIP makes no warranty for the accuracy of data supplied for its annual reports by the Pima Agency or the San Carlos Irrigation and Drainage District on water to lands, acreage irrigated, or annual crop reports.

Lateral Recharge

Recharge was also estimated for small laterals within agricultural and urban areas throughout the SRV. These laterals consist of piped laterals, open laterals, and ditches. The SRP canal system was used to estimate the types and densities of small laterals per section for both urban and agricultural areas. The SRP canal system was used because sufficient data exist to quantify the types and densities of small laterals throughout the SRP service area. The methodology for estimating recharge from these small laterals consisted of determining an average density of each lateral type per section and assuming a representative infiltration rate per length for each lateral type. Five case studies were selected to determine the density of each lateral type per "typical" urban and agricultural area. Three urban areas were selected that include the types and density of small laterals within central Phoenix, Phoenix-Scottsdale boundary, and Tempe-Mesa area, approximately a total of 58 square miles. The two agricultural areas selected to determine the types and density of small laterals were in the west valley and southeast valley, approximately a total of 53 square miles.

A SRP Zanjero Booklet (SRP, 1986) was used to determine the length of each small lateral type per square mile. Infiltration rates for each small lateral type were obtained from the Southwest Alluvial Basins Regional Aquifer Systems of America (SWAB-RASA) report (USGS, 1980) and the USBR (1989a). Open laterals and ditches were assumed to be lined with concrete in fair condition and to have a uniform construction dimension of 3 feet wide and 2 feet deep. Piped laterals were assumed to be constructed with concrete in good condition and to have a uniform diameter of 2 feet. Similar to estimating the recharge from other SRP canals, a wetted area per unit length was estimated for each type of lateral and an infiltration rate was multiplied by the total wetted area per square mile.

The average recharge per section estimated from the three urban case studies was 50 acre-feet/sq.mi/year. The average recharge from the two agricultural case studies was estimated at 130 acre-feet/sq.mi/year (Table 7). The results of using this methodology indicate that agricultural areas have a higher total lateral loss than urban areas. This may be attributed to the greater density of open laterals in agricultural areas.

5) Artificial Lake Recharge

Artificial lakes with surface areas greater than 10 acres within the SRV were considered as potential sources of localized groundwater recharge. The maximum potential recharge from artificial lakes with surface areas greater than 10 acres from 1978 to 1988 ranged between 7,000 acre-feet per year and 13,000 acre-feet per year dependant upon the infiltration rate selected and when the lakes were constructed.

Artificial lakes within the SRV were identified using data provided by the Phoenix AMA staff. The number of artificial lakes with surface areas greater than 10 acres within the SRV study area for 1978 and 1988 were 27 and 41, respectively. Lake surface area size and construction characteristics were considered the main factors in determining the maximum potential infiltration volumes (Table 12).

A survey was conducted by ADWR during July 1989 to determine the date of construction of each lake and general construction characteristics. The results of the survey indicated that of the 41 artificial lakes with surface areas greater than 10 acres, 15 were lined with a soil cement or soil conditioner SS-13 (Soil Science International, 1990), 12 were lined with a PVC liner, 7 were lined with compacted native soil or clay, 8 were unknown and 1 was unlined.

The maximum potential recharge from artificial lakes was estimated by multiplying the maximum surface area of each lake by a representative infiltration rate by the number of years the lake existed between 1978 and 1988. Infiltration rates for either clay lined or unlined lakes were adopted from tests conducted by the SRP on the Chaparral and Vista del Camino Lakes located in Scottsdale during December 1980. These tests estimated infiltration rates between 6.6 and 9.5 feet/year and are representative of lakes lined with a clay and salt mixture (SRP, 1981). Infiltration rates for lakes lined with PVC or soil conditioner SS-13 were assumed to be less than one foot per year. The volume of recharge estimated from all lakes was calculated annually to take into account the addition of each new artificial lake.

Table 12
Estimated Maximum Potential Recharge From Artificial Lakes With Surface Areas Greater Than 10 Acres In The SRV Study Area 1978-1988

Name	*Water Surface Area (Acres) (1)*	*Cadastral Location (1)*	*Type of Lining (2)*	*Total Water Reported (AF/YR) (3)*		*Infiltration Rate (Ft/Yr)*
				1987	**1988**	
Phoenix Zoo	17.5	T1N R4E Sec 4	unlined	0	0	9.5
Dobson Ranch Homeowners	75.6	T1N R5E Sec 31	unknown	1276	1488	9.5
Leisure World G.C.	11.2	T1N R6E Sec 25	clay	956	893	9.5
Leisure World H.O.A.	12.4	T1N R6E Sec 25	clay	75	0	9.5
Superstition Springs G.C.	26.0	T1N R6E Sec 36	SS-13 & clay	956	857	1.0
Garden Lakes	38.6	T2N R1E Sec 30	SS-13	471	606	1.0
Alvord Park	27.4	T1S R6E Sec 3	soil cement	693	360	9.5
Lakewood	40.0	T1S R3E Sec 36	unknown	615	736	9.5
The Lakes Community Assoc.	49.1	T1S R4E Sec 2	soil cement	403	464	9.5
Kiwanis Park	12.7	T2S R4E Sec 3	soil cement (?)	376	424	9.5
ASU Research Park	18.2	T1S R4E Sec 13	PVC ?-mil thickness	294	318	1.0
Ahwatukee/ Ahwatukee G.C.	29.1	T1S R4E Sec 18	PVC ?-mil thickness	1279	1323	1.0
Gila Springs	11.1	T2S R4E Sec 27	native soil	0	0	9.5
Estrella	67.6	T1S R5E Sec 14	SS-13	3252	2386	1.0
The Islands	78.2	T2S R5E Sec 14	SS-13	1187	1040	1.0
Anderson Springs	10.9	T1S R5E Sec 19	SS-13	0	0	1.0
The Springs	24.9	T1S R5E Sec 35	SS-13 & PVC	119	132	1.0
Val Vista Lakes	75.3	T2S R6E Sec 4	SS-13	1012	1036	1.0
Wigwam Golf & C.C.	12.2	T2N R1W Sec 22	SS-13	2437	2327	1.0
Arizona Biltmore C.C.	12.3	T2N R3E Sec 13	SS-13	898	901	1.0
McCormick Ranch G.C.	88.0	T2N R4E Sec 2	clay & salt	1575	1625	9.5
Chaparral Lake	10.6	T2N R4E Sec 13	clay & Salt	428	360	9.5

Table 12 Cont'd.

Name	*Water Surface Area (Acres) (1)*	*Cadastral Location (1)*	*Type of Lining (2)*	*Total Water Reported (AF/YR) (3)*		*Infiltration Rate (Ft/Yr)*
				1987	**1988**	
Pecos Ranch	12.0	T2S R5E Sec 5	unknown	0	77	9.5
Ocotillo Community Assoc.	92.9	T2S R5E Sec 17	PVC 20-mil	876	673	1.0
Oakwood Hills	14.8	T2S R5E Sec 28	SS-13	378	0	1.0
Sun Lakes Community Assoc.	36.6	T2S R5E Sec 31	SS-13 & PVC	497	577	1.0
Sun Lakes Cottonwood G.C.	10.3	T2S R5E Sec 32	SS-13	799	748	1.0
Sun City Lakes East G.C.	37.5	T3N R1E Sec 8	unknown	505	477	9.5
Sun City Dawn Lake	37.5	T3N R1E Sec 9	unknown	0	0	9.5
Sun Harbor Community Assoc.	48.3	T3N R1E Sec 10	unknown	128	129	9.5
Sun City Viewpoint Lake	37.5	T3N R1E Sec 17	unknown	188	0	9.5
Lake Biltmore Village	22.8	T3N R2E Sec 23	unknown	183	62	9.5
Tournament Players Club	16.8	T3N R4E Sec 3	PVC 12-mil	982	1000	1.0
Gainey Ranch G.C.	18.3	T3N R4E Sec 26	PVC 20-mil	1059	1133	1.0
McCormick Ranch P.O.A.	33.2	T3N R4E Sec 36	clay & salt	326	488	9.5
Scottsdale Ranch Community	47.9	T3N R5E Sec 29	PVC 20-mil	493	384	1.0
Fountain Hills Ranch	28.5	T3N R6E Sec 14	Rubber ?-mil	382	0	1.0
Ventana Lakes	34.8	T4N R1E Sec 19	PVC 20-mil	163	154	1.0
Arrowhead Ranch C.C.	21.9	T4N R1E Sec 25	PVC 20-mil	0	862	1.0
Sun City West Hillcrest	23.7	T4N R1W Sec 27	PVC 20-mil	795	763	1.0
Arrowhead Lakes	111.7	T4N R2E Sec 20	PVC 20-mil	0	0	1.0
Total				26,046	24,763	

Notes:
1. Data from the Phoenix AMA, only lakes with surface area greater than 10 acres
2. Type of lining obtained from telephone survey conducted by ADWR, June 1989
3. Data provided by the Phoenix AMA, total water use reported (surface water and groundwater)

6) Effluent Recharge

There are five wastewater treatment plants (WWTPs) within the SRV study area that discharge all or a portion of their treated effluent to the Salt, Gila, or Agua Fria Rivers (ADWR, 1989). These plants include the City of Phoenix 23rd and 91st Avenue WWTPs, Avondale WWTP, Goodyear WWTP, and Luke AFB WWTP which discharge treated effluent into the Gila or Agua Fria river channels where it becomes available for recharge. However, the two City of Phoenix WWTPs are the only plants that are considered to treat and discharge a significant volume of effluent that might attribute to groundwater recharge on a regional scale. A total of approximately 1.7 million acre-feet of treated effluent were discharged into the Salt River by the two City of Phoenix wastewater treatment plants between 1978 and 1988. The maximum potential recharge from treated effluent was estimated to be approximately 439,000 acre-feet. The methodologies utilized to estimate the maximum potential recharge from effluent are discussed below.

Recharge from treated effluent discharged from the City of Phoenix 23rd and 91st Avenue WWTPs was estimated using monthly discharge measurements, deliveries to the Arizona Nuclear Power Project - Palo Verde Plant (ANPP), downstream extent of the discharged effluent, and transient model results (ADWR, 1992b). The City of Phoenix provided monthly discharge measurements for both WWTPs (City of Phoenix, 1989a) and deliveries to the ANPP (City of Phoenix, 1989b). The annual volume of discharged effluent, estimated recharge from each WWTP and ANPP deliveries is presented in Table 13.

Table 13
Estimated Maximum Potential Recharge From Effluent Releases At The City Of Phoenix Waste Water Treatment Plants 23rd And 91st Avenue 1978-1988
(Figures Rounded to Nearest 100 Acre-Feet)

	23rd Avenue		91st Avenue	ANPP	Actual 91st Avenue	
Year	*Discharge (1)*	*Recharge (2)*	*Discharge (3)*	*Deliveries (4)*	*Discharge (5)*	*Recharge (6)*
1978	30,600	30,600	97,100	0	97,100	9,200
1979	36,100	36,100	98,800	0	98,800	9,200
1980	37,900	37,900	98,300	0	98,300	9,200
1981	40,200	40,200	114,900	0	114,900	9,200
1982	33,500	33,500	121,200	1,100	120,100	9,200
1983	24,400	24,400	139,700	600	139,100	9,200
1984	16,300	16,300	151,100	2,100	149,000	9,200
1985	15,100	15,100	158,800	2,300	156,500	9,200
1986	30,800	30,800	148,600	18,600	130,000	9,200
1987	36,000	36,000	151,000	26,000	125,000	9,200
1988	36,600	36,600	150,200	46,500	103,700	9,200
Total	337,500	337,500	1,429,700	97,200	1,332,500	101,200

Notes:

1) Discharge measurements provided by the City of Phoenix (City of Phoenix, 1989a). These measurements do not reflect the volume of waste activated sludge that is transferred to the 91st Ave WWTP. Actual discharge measurements require the subtraction of the transfers, which are typically less than 10 per cent of the total discharge.

2) Recharge estimates assume 100% of discharged effluent recharges groundwater system. Values rounded to nearest 100 AF.

3) Discharge measurements provided by the City of Phoenix (City of Phoenix, 1989a). These measurements do not reflect the volume of water delivered to the ANPP or the volume of waste activated sludge transferred from the 23rd Ave WWTP. Actual discharge measurements into the Salt River must subtract the ANPP deliveries.

4) Arizona Nuclear Power Project (ANPP) deliveries provided by the City of Phoenix (City of Phoenix, 1989b).

5) Values reflect the subtraction of ANPP deliveries.

6) Recharge estimate based on ADWR model estimated recharge between 91st Avenue WWTP and Buckeye Heading (ADWR, 1992b). This rate was assumed constant for the period 1978-1988, although minor annual variations actually existed.

The maximum potential recharge from the 23rd Avenue WWTP was estimated by assuming approximately 100 percent of the discharged effluent infiltrated along the Salt River between the plant and 67th Avenue. This is based upon field observations during September 1989. The actual volume of water discharged into the Salt River from 23rd Avenue WWTP is equal to the total inflow into the WWTP minus the volume of waste activated sludge that is transferred to the 91st Avenue WWTP (City of Phoenix, 1989a). However, the monthly volume of waste activated sludge was not readily available from the City of Phoenix records and was considered to be less than 10 percent of the total effluent discharged from the 23rd Avenue WWTP.

The downstream extent of the discharged effluent from the 23rd Avenue WWTP during September 1989 was observed to stop flowing between 59th and 67th Avenues. The areal extent of discharged effluent during September 1989 was considered representative for all years. Recharge from the 23rd Avenue WWTP was distributed in the model as a weighted average of the total lineal reach of effluent discharge within the Salt River per section between the plant and 67th Avenue for each year.

Under normal conditions effluent recharge from the 91st Avenue WWTP occurs between the plant and the Buckeye Heading, where most of the effluent is diverted into the Buckeye Canal. The recharge from effluent flows provided by the 91st Avenue WWTP has varied substantially with time. Initially recharge was high when the plant was first constructed in 1958. At that time the depth to water was greater than it is currently in that area. Prior to 1965 channel losses in the 6.5 mile reach between 91st Avenue and the Buckeye Heading amounted to about 35 percent of the 91st Avenue discharge (Halpenny and Green, 1975). After the 1965-1966 flood event on the Salt and Gila Rivers water levels rose, and the losses declined to about 26 percent (Halpenny and Green, 1975).

Effluent recharge has continued to decline since 1966 due to the gradual rise in water levels. Reduced effluent losses were proposed by Halpenny (1987) who stated that there is essentially no recharge due to effluent flows from the confluence of the Salt and Gila Rivers to Gillespie Dam. By the mid 1980's the depth to water was generally less than 10 feet along most of the reach between the 91st Avenue WWTP and the Buckeye Heading (Montgomery and Associates, 1988). The rise in water levels has reduced effluent recharge to the point that it amounts to little more than the ET losses which occur along that reach of the river. The ADWR model has provided estimates of recharge along the reach between the 91st Avenue WWTP and the Buckeye Heading which average approximately 9,200 acre-feet per year (ADWR, 1992b). The ET losses along the same reach are estimated at approximately 7,700 acre-feet per year (ADWR, 1992b).

7) Major Drainage Recharge

Estimating the maximum potential recharge from the four major river drainages (Salt, Agua Fria, Gila Rivers, and Queen Creek) within the SRV model domain was a major task. Recharge along the Salt River was estimated using water budget and infiltration rate methodologies. Recharge was estimated along the Agua Fria River the Gila River, and Queen Creek using water budget methodologies.

Approximately 10.7 million acre-feet flowed into the model domain along the four major drainages between calendar years 1978 and 1988. The total estimated maximum potential recharge from flood flows within the study area was approximately at 3.3 million acre-feet. Table 14 presents the estimated maximum potential annual recharge from each major drainage. It should be noted that these recharge estimates are based on above average streamflow during the period 1978 to 1988, and are not necessarily a reflection of the long-term averages. A detailed description of the methodologies used to estimate recharge from each river within the model domain is discussed below.

Table 14
Estimated Maximum Potential Recharge From The Major Drainages Within The SRV Study Area
1978-1988
(Figures Rounded to Nearest 100 Acre-Feet)

Calendar Year	*Salt River*	*Agua Fria River*	*Gila River*	*Queen Creek*
1978	347,300	70,200	54,300	23,600
1979	499,300	114,600	3,500	18,900
1980	515,300	177,000	71,500	9,800
1981	100	-0-	1,900	1,500
1982	44,600	-0-	2,000	1,900
1983	436,100	98,300	222,000	9,200
1984	67,800	-0-	88,700	4,200
1985	193,400	-0-	119,500	4,500
1986	8,400	-0-	18,300	2,100
1987	29,800	-0-	-0-	1,500
1988	20,400	-0-	-0-	1,800
Total	2,162,500	460,100	581,700	79,000

Salt River Recharge

The estimation of recharge along the Salt River due to sporadic releases from the Granite Reef Dam was a major challenge. Various estimates of recharge volumes have been provided by researchers over the past 25 years. Briggs and Werho (1966) provided infiltration and recharge estimates from the Salt River flow of April 1965. ADWR provided estimates of recharge from the flood flows of 1972 to 1976 (Long and others, 1982). Mann and Rohne (1983) estimated streamflow losses along the Salt and Gila Rivers from February 1978 to June 1980. ADWR made estimates of streamflow losses along the Salt River near the Indian Bend Wash area from 1983 to 1988 (ADWR, 1990). The Salt River Project has made preliminary estimates of infiltration rates in the Salt River channel at the Granite Reef Underground Storage Project (GRUSP) site (SRP, 1993b). The various recharge volumes and infiltration rates developed by these researchers are summarized in Table 15.

Table 15
Summary Of Various Estimates Of Groundwater Recharge And Infiltration Rates For Flood Flows On The Salt River 1966-1990

Study	*Estimated Infiltration Rates*	*Total Recharge Volume*	*Comments*
Briggs and Werho (1966)	1.1 to 2.5 feet-day	20,000 acre-feet	82-hour release into the Salt River channel.
Long and others (1982)	1,250 acre-feet/year per mile of channel	---------------	Estimates for recharge during the 1972-1977 period.
Mann and Rohne (1983)	.44 to 1.3 feet/day .91 feet/day average	474,000 acre-feet	Estimated recharge from Granite Reef to Gillespie Dams February 1978 to June 1980.
ADWR (1990b)	.91 feet/day	320,700 acre-feet	Estimated recharge along Salt River from Granite Reef Dam to Tempe Butte 1983-1985.
SRP (1993b)	1.5-2.0 feet/day	---------------	Preliminary estimated recharge rates at GRUSP site.

A review of the published data was undertaken to determine the most appropriate method for estimating stream channel recharge along the Salt River. Two methods were studied to determine their applicability: 1) the water budget method, and 2) the infiltration rate method. The water budget method was based on determining inflow and outflow along various channel reaches, and assuming the difference between inflows and outflows was equal to the total volume of recharge. The infiltration rate method was based on determining the inundated channel area during a period of flow, and multiplying the inundated area by an infiltration rate to estimate the total volume of recharge.

The water budget methodology provided estimates of recharge along the Salt River from 1978 to 1988. The water budget method consisted of determining the gaged inflows to the Salt River at Granite Reef Dam, and subtracting from those inflows the gaged outflow of system on the Gila River above the diversions at Gillespie Dam. Additions to flow from the Gila, Santa Cruz, and Agua Fria Rivers were subtracted from the outflow totals at Gillespie Dam. Also subtracted from the outflow at Gillespie Dam was a baseflow component which ranged from 300 acre-feet per day to 800 acre-feet per day during the time of Granite Reef discharge. The baseflow component represents effluent and ungaged irrigation return flows which enter the system downstream from the City of Phoenix 91st Avenue WWTP. The water budget analysis was based on the following assumptions and simplifications:

1) Evaporation was insignificant during the period of flooding.
2) All inflows from the Gila and Santa Cruz Rivers near Laveen, and the Agua Fria River at Avondale passed through the system undiminished.

3) Additions to flow from Indian Bend Wash, Waterman Wash, Centennial Wash, and the Hassayampa River were indeterminable due to lack of complete mean daily flow data, and considered negligible.

4) Gaged inflows, outflows, and estimated baseflow were determined only for the period of discharge at Granite Reef Dam. Therefore, the flow figures are not annual totals for the Gila, Santa Cruz, and Agua Fria gages.

The flow data and maximum potential recharge estimates using the water budget methodology are tabulated in Table 16. Examination of the data shows that outflows exceeded inflows during the 1980 period of Salt River discharge. This is a condition which precludes the calculation of recharge using the water budget methodology. Possible explanations for this observation include: 1) substantial ungaged inflows such as irrigation tail water, unused canal water, and tributary flows existed, 2) gaging inaccuracies existed, 3) baseflow was underestimated. It is likely that a combination of these factors contributed to the situation. Regardless of the explanations, the data demonstrate that it was not possible to use the stream gage data to accurately estimate recharge during the flood flows of 1980 along the Salt River. The water budget methodology provided an estimate of the maximum potential recharge from Salt River flows for the period 1978-1988 which was approximately 1.0 million acre-feet. The estimated recharge is about 12 percent of the total Granite Reef Dam discharge for that time period.

Table 16
Estimated Maximum Potential Recharge Along The Salt River From Granite Reef Dam To The 91st Avenue WWTP 1978 To 1988
(Water Budget Methodology)
(Figures Rounded to Nearest 100 Acre-Feet)

Calendar Year	*Monthly Period*	*Granite Reef Discharge Days*	*Salt River Inflow Granite Reef 9511500*	*Gila River Inflow Laveen 9479500 (1)*	*Santa Cruz River Inflow Laveen 9489000 (1)*	*Agua Fria Inflow Avondale 9513970 (1)*	*Gila River Inflow Estimated Baseflow (1),(2)*	*Gila River Outflow Gillespie Dam 9518000 (1)*	*Estimated Maximum Potential Recharge (3)*	*Recharge as Percentage of Granite Reef Discharge*
1978	1-9	46	593,700	12,300	5,900	49,700	22,800	610,800	73,600	
	10-12	15	795,600	31,700	15,200	31,900	7,400	722,300	159,500	16.8%
	Annual Totals	61	1,389,300	44,000	21,100	81,600	30,200	1,333,100	233,100	
1979	1-9	149	1,997,100	102,600	30,400	40,300	81,700	2,030,500	221,600	
	10-12	0	0	0	0	0	0	0	0	11.1%
	Annual Totals	149	1,997,100	102,600	30,400	40,300	81,700	2,030,500	221,600	
1980	1-9	126	2,061,300	25,900	700	168,500	61,400	2,339,400	-21,600	
	10-12	1	100	0	0	0	200	200	100	-1.0%
	Annual Totals	127	2,061,400	25,900	700	168,500	61,600	2,339,600	(4) - 21,500	
1981	1-9	2	100	0	100	0	800	900	100	
	10-12	1	0	0	0	0	100	100	0	100.0%
	Annual Totals	3	100	0	100	0	900	1,000	100	
1982	1-9	19	81,100	200	200	0	5,900	26,600	60,800	
	10-12	25	97,200	100	2,400	(5)	10,900	71,300	39,300	56.1%
	Annual Totals	44	178,300	300	2,600	(5)	16,800	97,900	100,100	
1983	1-9	170	1,172,800	3,500	24,700	(5)	76,800	1,243,000	34,800	
	10-12	50	571,600	175,200	111,200	(5)	27,800	685,500	200,300	13.5%
	Annual Totals	220	1,744,400	178,700	135,900	(5)	104,600	1,928,500	235,100	
1984	1-9	21	36,400	15,500	0	(5)	26,000	43,700	34,200	
	10-12	11	234,800	1,300	5,500	(5)	5,900	192,700	54,800	32.8%
	Annual Totals	32	271,200	16,800	5,500	(5)	31,900	236,400	89,000	
1985	1-9	154	717,800	191,300	7,600	(5)	66,300	923,000	60,000	
	10-12	33	55,600	100	300	(5)	18,000	33,200	40,800	13.0%
	Annual Totals	187	773,400	191,400	7,900	(5)	84,300	956,200	100,800	

Table 16 Cont'd.

Calendar Year	Monthly Period	Granite Reef Discharge Days	Salt River Inflow Granite Reef 9511500	Gila River Inflow Laveen 9479500 (1)	Santa Cruz River Inflow Laveen 9489000 (1)	Agua Fria Inflow Avondale 9513970 (1)	Gila River Inflow Estimated Baseflow (1),(2)	Gila River Outflow Gillespie Dam 9518000 (1)	Estimated Maximum Potential Recharge (3)	Recharge as Percentage of Granite Reef Discharge
1986	1-9	33	7,500	0	0	(5)	4,800	5,700	6,600	
	10-12	7	900	0	0	(5)	3,300	3,300	900	89.3%
	Annual Totals	40	8,400	0	0	(5)	8,100	9,000	7,500	
1987	1-9	37	29,000	0	300	(5)	21,600	38,000	12,900	
	10-12	5	800	0	400	(5)	3,400	3,800	800	46.0%
	Annual Totals	42	29,800	0	700	(5)	25,000	41,800	13,700	
1988	1-9	18	19,400	0	200	(5)	10,300	10,500	19,400	
	10-12	4	1,000	0	500	(5)	4,300	4,900	900	99.5%
	Annual Totals	22	20,400	0	700	(5)	14,600	15,400	20,300	
1978-1988 Totals		927	8,473,800	559,700	205,600	290,365	459,700	8,989,400	999,800	11.8%

Notes:

1) Gaged flows and estimated baseflow only during period of flooding on the Salt River, not annual totals. USGS gage accuracy rated at ± 5 per cent (USGS, 1993).

2) Baseflow accounts for effluent releases, irrigation return flows, and other ungaged inflows to the Salt-Gila system. Baseflow rates estimated by evaluating Gillespie Dam outflows immediately preceding and following flood events. Estimated baseflow rates varied with each flood event, with estimated baseflow ranging from about 300 acre-feet per day to 800 acre-feet per day. Baseflow totals calculated as the product of the estimated baseflow rate during flood and the number of days of flooding.

3) Estimated Maximum Potential Recharge = Salt River Inflow - (Gila Outflow - (Gila Inflow + Santa Cruz Inflow + Agua Fria Inflow + Estimated Baseflow)).

4) 1980 maximum potential recharge less than zero. Probable extreme gaging inaccuracies existed for this year. The 1978-1988 total recharge should be increased to account for this discrepancy.

5) Agua Fria gage discontinued in 1982.

A modified version of the infiltration method was used to provide a second estimate of recharge along the Salt River from 1978 to 1988. The methodology was based on the results of ADWR's study of recharge along the Salt River in the Indian Bend Wash area (ADWR, 1990a). The results of that study were based on the examination of air photos of flood events along the Salt in the 1970's and the early 1980's. The study showed that flows ranging from about 4,000 cubic feet per second (cfs) to 30,000 cfs followed almost identical paths in the river channel, and that only flows which exceeded 100,000 cfs flowed over the existing banks. The average wetted channel area was determined from the Granite Reef Dam to the Indian Bend Wash area near Tempe Butte using aerial photos. Recharge was estimated as the product of the wetted area, the period of flooding, and the infiltration rate of .91 feet per day (Mann and Rohne, 1983). Using this methodology it was estimated that the average annual recharge along the Salt River from Granite Reef Dam to Tempe Butte was approximately 12 percent of the annual Granite Reef Dam discharge (ADWR, 1990b). Recharge from Tempe Butte to the 91st Avenue WWTP was assumed to be approximately equal to the recharge from Granite Reef Dam to Tempe Butte since both reaches are of approximately equal length (15 miles). Therefore, the estimated maximum potential recharge from Granite Reef Dam to the 91st Avenue WWTP was estimated to be approximately 25 percent of the annual discharge at the Granite Reef Dam (Table 17). For years with low discharge, 1981 and 1986 through 1988, all water discharged at Granite Reef Dam was assumed to be recharged.

The results of the water budget and infiltration rate methodologies indicate that the maximum potential recharge from long-term (greater than 60 days) flood events on the Salt River ranges from approximately 12 percent to 25 percent of the total annual discharge at Granite Reef

Table 17
Estimated Maximum Potential Recharge Along The Salt River From Granite Reef Dam To The 91st Avenue WWTP 1978-1988 (Infiltration Rate Methodology)
(Acre-feet)

Calendar Year	*Granite Reef Dam Discharge (1)*	*Estimated Infiltration Volume (2)*	*Recharge as Percentage of Granite Reef Discharge*
1978	1,389,300	347,300	25%
1979	1,997,100	499,300	25%
1980	2,061,400	515,300	25%
1981	100	100	100%
1982	178,300	44,600	25%
1983	1,744,400	436,100	25%
1984	271,200	67,800	25%
1985	773,400	193,400	25%
1986	8,400	8,400	100%
1987	29,800	29,800	100%
1988	20,400	20,400	100%
Total	8,473,800	2,162,500	25%

Notes:

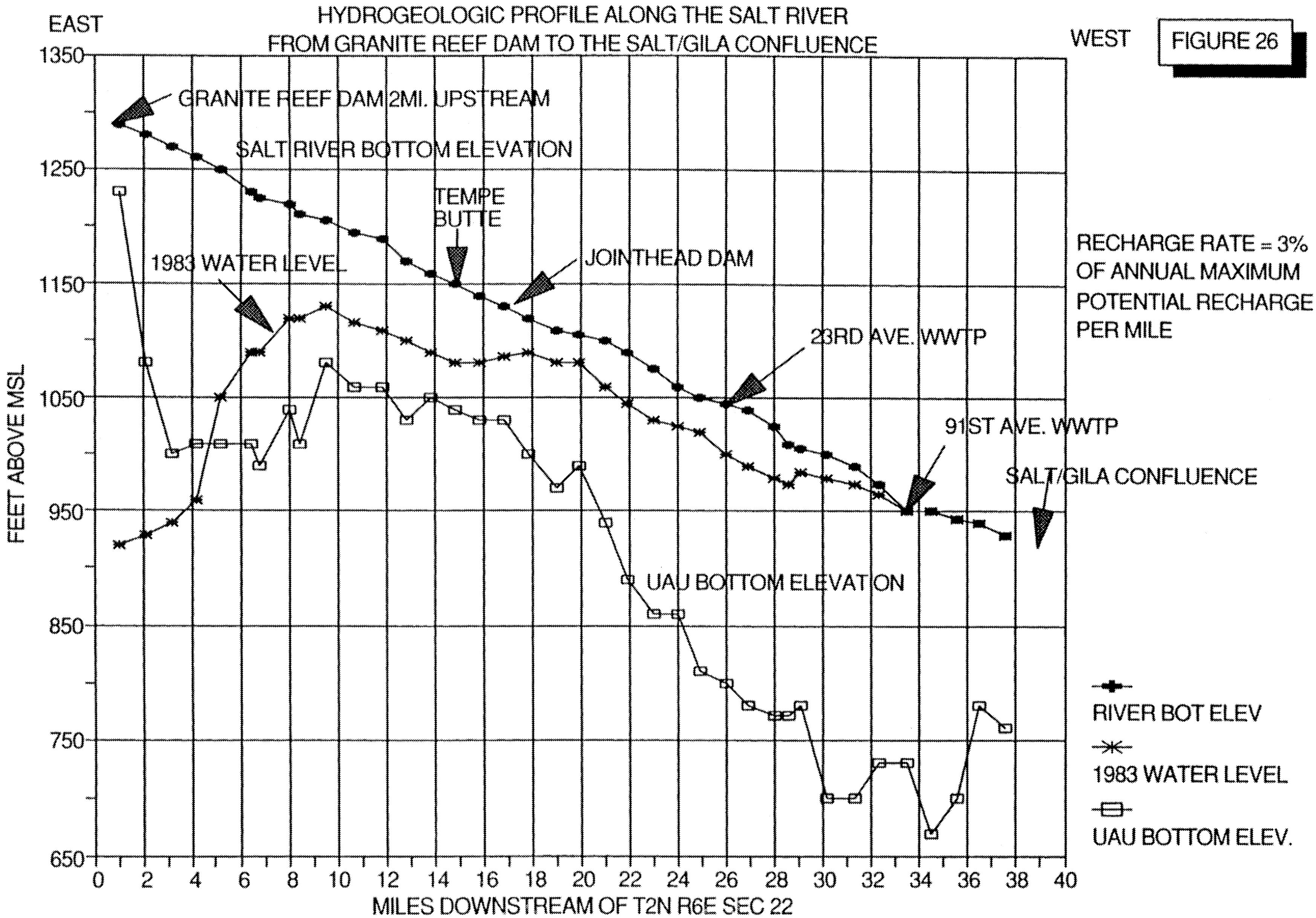
1) Discharge measurements obtained from the Salt River Project Measurements rounded to the nearest 100 AF.

2) Infiltration volume estimates based upon the analysis of wetted channel area, and average infiltration rate of .91 feet/day (ADWR, 1990b).

Dam. For modeling purposes the higher value of 25 percent was selected as the maximum potential recharge rate for initial model input. The results also indicate that the amount of recharge is variable and dependent upon several factors which include: 1) the length of time of discharge, 2) the total volume of discharge, 3) antecedent soil moisture conditions, 4) the depth-to-water below and near the river channel. Regardless of the methodology chosen, the results indicate that recharge from Salt River flood flows during the period 1978 to 1988 was a significant quantity of water, estimated to be at least 1.0 million acre-feet, but no greater than 2.2 million acre-feet in volume.

The recharge was initially distributed in the model as a weighted average proportional to the length of river reach per section. This approach was later modified in recognition of the fact that factors such as depth to water, UAU transmissivity, and shallow bedrock substantially effect infiltration rates (Figure 26). The recharge was redistributed based on consideration of these factors and on preliminary model results (ADWR, 1992b). No recharge was distributed downstream of the 91st Avenue WWTP due to the shallow depth to water in that area, which would prevent any significant recharge from flood flows in the river.

FIGURE 26



HYDROGEOLOGIC PROFILE ALONG THE SALT RIVER
FROM GRANITE REEF DAM TO THE SALT/GILA CONFLUENCE
EAST
WEST
GRANITE REEF DAM 2MI. UPSTREAM
SALT RIVER BOTTOM ELEVATION
TEMPE BUTTE
1983 WATER LEVEL
JOINTHEAD DAM
23RD AVE. WWTP
91ST AVE. WWTP
SALT/GILA CONFLUENCE
UAU BOTTOM ELEVATION
RECHARGE RATE = 3% OF ANNUAL MAXIMUM POTENTIAL RECHARGE PER MILE
FEET ABOVE MSL
1350
1250
1150
1050
950
850
750
650
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
MILES DOWNSTREAM OF T2N R6E SEC 22
RIVER BOT ELEV
1983 WATER LEVEL
UAU BOTTOM ELEV.

Agua Fria River Recharge

Recharge was estimated for the Agua Fria River using the water budget methodology. This approach was appropriate because ungaged tributary inflows were minimal, and gaging inaccuracy was probably less due to the comparatively low volume of flow. Streamflow gaging data from the Waddell Dam indicates that the dam intermittently spilled water into the normally dry riverbed in only four years between 1978 and 1988 (USBR, 1989b). Waddell Dam releases and additions to flow from Skunk Creek, New River, Arizona Canal tailwater, and Grand Canal tailwater totalled approximately 759,000 acre-feet. The Agua Fria River flow at Avondale totalled approximately 298,000 acre-feet per year. The estimated maximum potential recharge was approximately 460,000 acre-feet (Table 18).

Recharge was distributed as a weighted function of the lineal length of river reach per section from the Waddell Dam to Avondale.

Table 18
Estimated Maximum Potential Recharge From The Agua Fria River 1978 To 1988
(Figures Rounded To Nearest 100 Acre-Feet)

	Waddell Dam Discharge	*New River Inflow*	*Skunk Creek Inflow*	*Grand Canal Inflow*	*Arizona Canal Inflow*	*Agua Fria Outflow*	*Estimated Recharge*
1978	104,300	35,300	2,900	3,700	5,800	81,800	70,200
1979	140,400	7,200	400	3,600	3,300	40,300	114,600
1980	302,300	31,100	900	3,500	7,800	168,600	177,000
1983	83,200	15,300	-0-	2,200	5,300	7,700	98,300
Total	630,200	88,900	4,200	13,000	22,200	298,400	460,100

Notes: 1) Measurements are based on USGS water years
2) Source: (USBR, 1989b)

Gila River Recharge

The maximum potential recharge from the Gila River within the SRV model domain was estimated using a water budget methodology. In general, infiltration volumes along the Gila River were estimated by taking into account the volume of water discharged at Ashurst-Hayden Dam, recharge along the Gila River outside of the study area (that is, between Ashurst-Hayden Dam and Sacaton), additions to flow along the Gila River downstream of Sacaton, within the study area and the outflow at the USGS gaging station 9479500 near Laveen. Approximately 1.55 million acre-feet were discharged from the Ashurst-Hayden Dam between the calendar years of 1978 and 1988 (SCIP, 1989). The methodology estimated approximately 582,000 AF of streamflow losses along the Gila River between Sacaton and the USGS gaging station near Laveen between 1978 and 1988 (Table 19).

The annual volume of water discharged at the Ashurst-Hayden Dam was obtained from the San Carlos Irrigation Project (SCIP, 1989). The annual volume of Gila River flood flows that entered the SRV study area near Sacaton were estimated from the ADWR Pinal AMA ground water flow modeling effort (Corkhill and Hill, 1990). Recharge between Ashurst-Hayden Dam and Sacaton was estimated and subtracted from the total flow discharged from the dam. Additions to flow downstream of Sacaton included the Gila Storm Drain operated by SRP and Lone Butte Waste Water Treatment Plant operated by the City of Chandler. Table 19 presents the discharge of the Ashurst-Hayden Dam, estimated flow of the Gila River near Sacaton from the ADWR Pinal AMA groundwater flow modeling effort, additions to flow, and the estimated volume of recharge along the Gila River within the SRV model domain.

Table 19
Estimated Maximum Potential Recharge Along The Gila River From Near Sacaton To Gila Crossing 1978-1988
(Figures Rounded to Nearest 100 AF)

			Gila River	
Calendar Year	***Ashurst-Hayden Dam Discharge (1)***	***Estimated Gila River Flow Near Sacaton (2)***	***Additions to Flow (3)***	***Recharge SRV Study Area***
1978	144,200	111,600	1,500	54,300
1979	109,300	106,700	2,500	3,500
1980	141,300	98,600	1,000	71,500
1981	14,500	0	1,900	1,900
1982	12,400	0	2,000	2,000
1983	545,500	413,900	400	222,000
1984	164,200	111,300	300	88,700
1985	382,000	311,000	300	119,500
1986	29,500	18,200	100	18,300
1987	800	0	100	0
1988	8,200	7,600	3,900	0
TOTALS	1,551,900	1,178,900	14,000	581,700

Notes:

1) Ashurst-Hayden Dam discharges reported by the San Carlos Irrigation Project (SCIP, 1989).

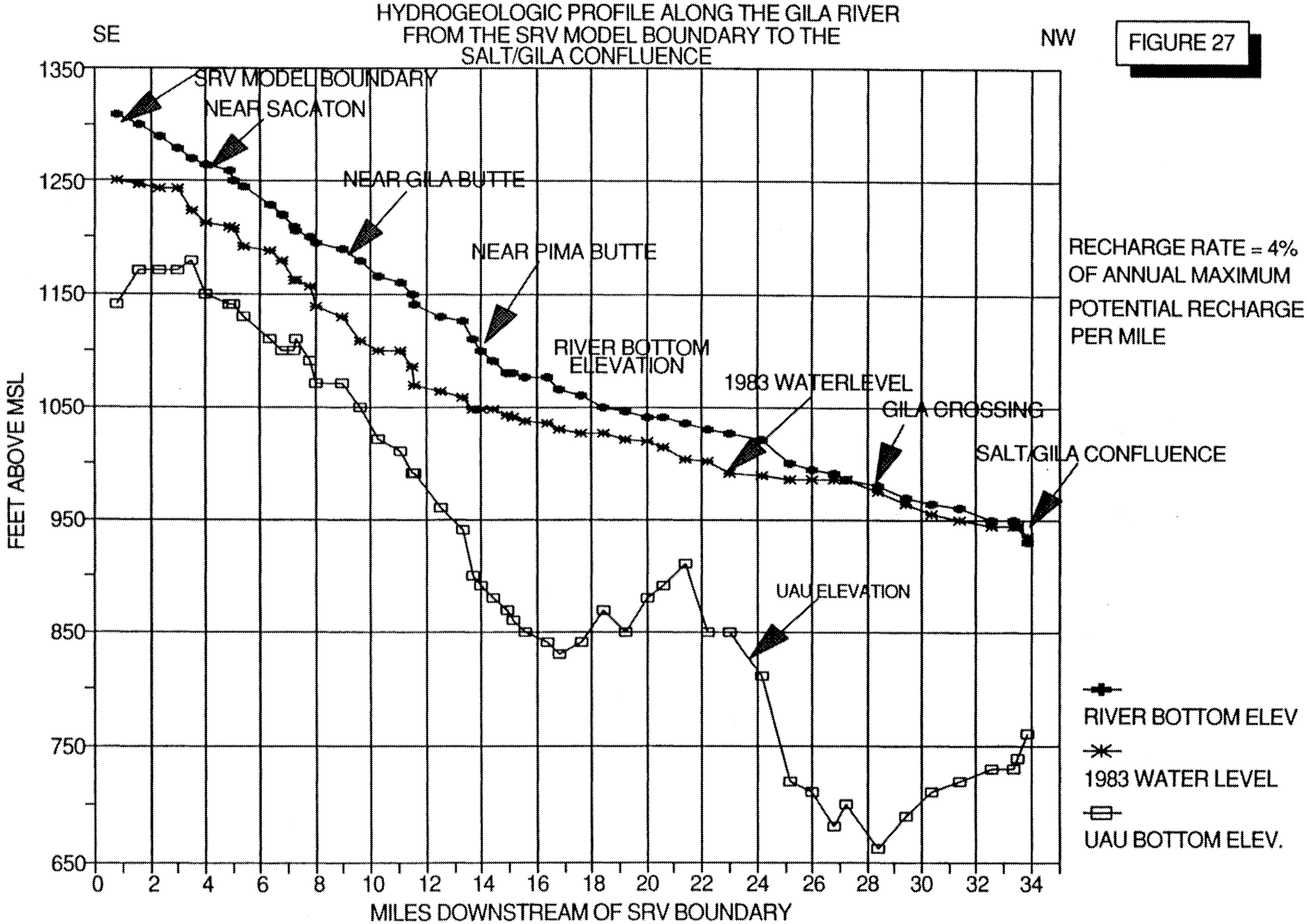
2) Estimates projected from the Pinal AMA groundwater flow model, Phase 2 report (Corkhill and Hill, 1990).

3) Additions to flow include the Gila Storm Drain and Lone Butte WWTP (City of Chandler) prior to 1982, and the City of Coolidge effluent.

The USGS estimated the amount of recharge along the entire Gila River between Ashurst-Hayden Dam and Laveen for 1983 at 329,000 acre-feet (USGS, 1989). The methodology used for this modeling effort estimated the total volume of recharge along the entire reach of the Gila River between Ashurst-Hayden Dam and the confluence with the Salt River at 353,000 acre-feet for 1983. This independent check for 1983 compares reasonably well with the USGS.

Recharge along the Gila River downstream of Gila Crossing was not assumed to exist. This assumption was based upon the shallow depth to water downstream from that location (Figure 27). Recharge was distributed as a weighted average proportional to the lineal length of river reach per section from near Sacaton to Gila Crossing. In the absence of historical water level data these groundwater conditions were assumed constant for all major floods.

FIGURE 27


HYDROGEOLOGIC PROFILE ALONG THE GILA RIVER
FROM THE SRV MODEL BOUNDARY TO THE
SALT/GILA CONFLUENCE
SE
NW
SRV MODEL BOUNDARY
NEAR SACATON
NEAR GILA BUTTE
NEAR PIMA BUTTE
RIVER BOTTOM ELEVATION
1983 WATERLEVEL
GILA CROSSING
SALT/GILA CONFLUENCE
UAU ELEVATION
FEET ABOVE MSL
MILES DOWNSTREAM OF SRV BOUNDARY
RECHARGE RATE = 4% OF ANNUAL MAXIMUM POTENTIAL RECHARGE PER MILE
RIVER BOTTOM ELEV
1983 WATER LEVEL
UAU BOTTOM ELEV.

Queen Creek Recharge

The water budget methodology was used to estimate recharge along Queen Creek. Approximately 78,800 acre-feet was discharged from the Whitlow Ranch Dam between 1978 and 1988. This methodology assumes that 100 per cent of the total discharges infiltrates along the entire reach of Queen Creek. It must be noted that the infiltration volumes estimated for Queen Creek have no field data to support them and only represent a first approximation of the maximum potential recharge.

In general, recharge was estimated by dividing the total monthly flows from Whitlow Ranch Dam into three classifications and assuming 100 percent of the flows infiltrate. This assumption was originally made by Babcock (1941) who studied infiltration along Queen Creek from flood events during 1941. Whitlow Ranch Dam discharge rates were provided by the Army Corps of Engineers (U.S. Army Corps of Engineers, 1989). Discharge rates of less than 1000 AF/month (Class 1) were assumed to infiltrate completely within 5-10 miles downstream of the dam. Discharge rates between 1,000 and 2,000 AF/month (Class 2) were assumed to infiltrate completely within 10-20 miles downstream of the dam. Discharge rates greater than 2,000 AF/month (Class 3) were assumed to infiltrate along the entire reach of Queen Creek. The classification of flows and downstream infiltration distance were selected arbitrarily since no streamflow gaging data existed. The total volume of recharge for each classification of flood flow was distributed as a weighted average of the lineal length of river reach per section. Table 20 presents the annual recharge per classification of flow from Whitlow Ranch Dam, volume of water within each flood classification, and total estimated volume of recharge.

Table 20
Estimated Maximum Potential Recharge From Queen Creek 1978-1988
(Figures Rounded to Nearest 100 AF)

		Subdivisions of Total Discharge			
Calendar Year	***Whitlow-Ranch Dam Total Discharge***	***Class 1 Flows (1)***	***Class 2 Flows (2)***	***Class 3 Flows (3)***	***Estimated Infiltration Volume***
1978	23,600	2,200	--	21,400	23,600
1979	18,800	2,200	--	16,600	18,800
1980	9,900	1,300	1,300	7,300	9,900
1981	1,500	1,500	--	--	1,500
1982	1,900	1,900	--	--	1,900
1983	9,200	1,500	1,900	5,800	9,200
1984	4,200	1,400	--	2,800	4,200
1985	4,500	1,300	3,200	--	4,500
1986	2,100	2,100	--	--	2,100
1987	1,500	1,500	--	--	1,500
1988	1,800	1,800	--	--	1,800
TOTAL	79,000				79,000

Notes:

1) Class 1: total discharges from Whitlow Ranch Dam, each individual monthly spill less than 1000 AF.

2) Class 2: total discharges from Whitlow Ranch Dam, each individual monthly spill between 1,000 and 2,000 AF.

3) Class 3: total discharges from Whitlow Ranch Dam, each individual monthly spill greater than 2,000 AF.

8) Mountain Front Recharge

Mountain front recharge comprises a small inflow to the modern regional groundwater system, although it may be locally important. As mentioned earlier mountain front recharge occurs mainly in the ESRV along the Superstition Mountains and McDowell Mountains. The volume of mountain front recharge has been assumed to be equal to the predevelopment estimates, or approximately 7,000 acre-feet per year.

9) Ephemeral Stream Recharge

Ephemeral stream recharge represents another small inflow to the modern groundwater system. Ephemeral stream channel infiltration was assumed to exist at the predevelopment levels for Cave Creek, Skunk Creek, and New River. The total annual recharge from these streams is estimated to average approximately 9,000 acre-feet per year (Figure 22). Recharge from Queen Creek was analyzed separately due to the large flows of 1978 through 1988 which significantly exceeded the predevelopment estimates of 2,000 acre-feet per year.

C. Groundwater Pumpage

1) General Background and 1978-1988 Pumpage Totals

Pumpage represents the major outflow from the modern groundwater system. It is estimated that approximately 83 million acre-feet of groundwater was pumped from the aquifers of SRV between 1915 and 1984 (USGS, 1986). Between 1984 and 1988 agricultural pumpage accounted for approximately 80 percent of the total reported pumpage in the SRV study area. Most of the remaining pumpage was divided between the municipal and industrial sectors with municipal pumpage comprising approximately 14 percent of the total pumpage, and industrial pumpage accounting for the remaining 6 percent (ADWR, 1992a).

Groundwater pumpage information for the SRV study area was collected for two time periods. Well-specific pumpage data was obtained for 1978 through 1983 from the pumpage records of major groundwater users. Major groundwater users included: irrigation projects, irrigation districts, municipalities, and water companies. Estimates of non-irrigation district agricultural, industrial, Indian, and small well (exempt) pumpage were added to the 1978-1983 totals. Well-specific pumpage data for 1984 through 1988 was derived from the ADWR-ROGR database. The 1984 through 1988 totals were also adjusted to account for Indian and exempt well pumpage. Annual groundwater pumpage totals in the SRV study area during the period 1978-1988 are listed in Table 21. It should be noted that the 1983 total pumpage was substantially less than the total pumpage for other years. This difference is explained by the fact that 1983 was a year of abnormally high precipitation and runoff, and a greater volume of inexpensive surface water was available to agricultural water users than in other years.

Table 21
Groundwater Pumpage In The SRV Study Area 1978-1988
(Figures Rounded to Nearest 1000 Acre-Feet)

	ROGR PUMPAGE (1)	*EST. NON-INDIAN WATER USERS (2)*	*EST. INDIAN PUMPAGE (2)*	*EST. EXEMPT PUMPAGE (3)*	*EST. TOTAL PUMPAGE*
1978	(4)	1,000,000	206,000	24,000	1,230,000
1979	(4)	945,000	176,000	24,000	1,145,000
1980	(4)	1,011,000	201,000	24,000	1,236,000
1981	(4)	1,523,000	267,000	24,000	1,814,000
1982	(4)	1,017,000	228,000	24,000	1,269,000
1983	(4)	609,000	166,000	24,000	799,000
1984	1,132,000	(4)	174,000	24,000	1,330,000
1985	877,000	(4)	113,000	24,000	1,014,000
1986	845,000	(4)	122,000	24,000	991,000
1987	806,000	(4)	104,000	24,000	934,000
1988	859,000	(4)	117,000	24,000	1,000,000

Notes:

1) Pumpage figures based on measured data reported to ADWR (ROGR-Database).

2) Pumpage figures based on reported data and estimates.

3) Pumpage figures based on estimates only, at 10 acre-feet per year per exempt well.

(4) Not Applicable.

2) Non-Indian Pumpage Estimates

Prior to 1984 there was no statutory requirement for ground-water users to report their pumpage to the ADWR. Therefore, it was necessary to request 1978-1983 pumpage data directly from groundwater users. All major groundwater use entities in the SRV were contacted to provide 1978-1983 pumpage data. The 1978-1983 reported pumpage totals were increased by adding estimated pumpage values for non-irrigation district agricultural and industrial wells. The increases were based on 1978-1983 USGS pumpage estimates for the SRV (USGS, 1986). An estimate of small well (exempt-type) pumpage was made for the SRV study area. Exempt wells are defined by law as wells which cannot pump more than 35 gallons per minute, nor pump more than 10 acre-feet per year. The number of exempt wells in the SRV was tabulated from the ADWR "55" wells database. The total number of exempt wells in the SRV study area was approximately 2,400. For the purposes of making an estimate of total exempt pumpage it was assumed that each well pumped 10 acre-feet per year, for a total maximum pumpage of 24,000 acre-feet per year.

3) Indian Pumpage Estimates

Due to a lack of information it was necessary to make estimates of Indian pumpage for the period 1978 through 1988.

Within the SRV study area there are two large Indian communities: the Salt River Pima-Maricopa Indian Community (SRPMIC), and the Gila River Indian Community (GRIC).

Groundwater pumpage on Indian lands is exempt from state regulation and reporting requirements, and annual pumpage records were only generally available for Indian wells on the GRIC which are owned by the San Carlos Irrigation Project (SCIP) (SCIP, 1978-1988). Pumpage for other large capacity irrigation wells on the SRPMIC and GRIC was estimated based on a water budget approach.

The water budget approach essentially computed an annual water use requirement for each Indian community based on an assumed value of effective consumptive use (consumptive use divided by irrigation efficiency) and reported cropped acreage provided by the U.S. Bureau of Indian Affairs (BIA) crop reports (U.S. Bureau of Indian Affairs, 1978-1988). Unreported pumpage for large capacity production wells was estimated for each Indian community by subtracting total surface water deliveries and any reported pumpage from the computed annual water use requirement.

Groundwater pumpage for agricultural irrigation occurs in two areas on the SRPMIC. North of the Arizona Canal pumpage occurs on the Wood and Taylor farms. The combined pumpage for these two farms in 1978 is estimated to have been about 17,500 acre-feet per year (Stetson Engineering, 1978). It was assumed that this rate is representative of the average rate from 1978 through 1988. South of the Arizona Canal the SRPMIC operates several large capacity wells which supplement SRP surface water deliveries to the community. Pumpage for these wells has been estimated for the periods 1978-1982, and 1986-1988. The SRPMIC provided well pumpage records to the ADWR for the period 1983-1985. Pumpage estimates for the SRPMIC from 1978-1988 are summarized in Table 22.

Table 22
Estimated Groundwater Pumpage On The Salt River Pima-Maricopa Indian Community 1978 - 1988
(Figures Rounded to Nearest 100 Acre-Feet)

	CROPPED ACRES (1)	EFF. C.U. (2)	EST. WATER USE	SRP SURFACE WATER (3)	WOOD & TAYLOR FARM PUMPAGE (4)	EST. OTHER PUMPAGE (5,6)	EST. TOTAL SRPMIC PUMPAGE
1978	8500	5.4	45,900	28,600	17,500	17,300	34,800
1979	8479	5.4	45,800	47,000	17,500	0	17,500
1980	8469	5.4	45,800	49,900	17,500	0	17,500
1981	8487	5.4	45,800	36,800	17,500	9,000	26,500
1982	7404	5.4	40,000	38,600	17,500	1,400	18,900
1983	8872	5.4	47,900	35,500	17,500	2,100	19,600
1984	8782	5.4	47,400	33,400	17,500	11,900	29,400
1985	5159	5.4	27,900	31,700	17,500	300	17,800
1986	6747	5.4	36,400	30,000	17,500	6,400	23,900
1987	7000	5.4	37,800	34,900	17,500	2,900	20,400
1988	7000	5.4	37,800	35,500	17,500	2,300	19,800

Notes:

1) This acreage does not include Wood and Taylor Farms acreage. Sources of data: SRPMIC annual water use reports, and BIA crop reports. 1978, 1987, 1988 BIA crop reports were unavailable at time of study, and therefore 1978 1987, and 1988 cropped acreages were estimated.

2) Effective Consumptive Use. Source: Stetson Engineering (1978).

3) SRP surface water deliveries to SRPMIC. Source: SRP (1989b).

4) Annual Pumpage Wood and Taylor farms estimated at 17,500 acre-feet. Source: Stetson Engineering (1978).

5) Estimated pumpage equals zero when annual SRP surface water delivery exceeds estimated water use.

6) 1983-1985 pumpage values supplied by SRPMIC.

Groundwater pumpage for agricultural irrigation occurs in several locations on the GRIC. In the northwestern portion of the community pumpage occurs in the Maricopa Colony and Laveen area (Township 1 South, Ranges 1,2 East). Further south and east pumpage occurs in the Gila Crossing, Lone Butte, Broad Acres, Lamb and FMT farm areas (Townships 1,2 South, Ranges 2,3,4 East). Pumpage occurs in the San Tan Ranch area (Township 3 South, Ranges 5,6 East), and also occurs from tribal wells located near Sacaton (Township 4 South, Range 6 East). The SCIP provides a combination of pumped groundwater and Gila River surface water to the southern section of the GRIC (Townships 3,4,5 South, Ranges 4,5,6,7 East). The annual SCIP pumpage on the GRIC averaged about 37,000 acre-feet per year for the period 1978-1988 (SCIP, 1978-1988). Pumpage estimates for other large capacity irrigation wells were prepared based on the previously discussed water budget methodology. Pumpage estimates for the GRIC from 1978-1988 are summarized in Table 23.

Table 23
Estimated Groundwater Pumpage On The Gila River Indian Community 1978-1988
(Figures Rounded to Nearest 100 Acre-Feet)

	CROPPED ACRES (1)	*EFF. C.U. (2)*	*EST. WATER USE*	*SCIP & OTHER SURFACE WATER TO LAND (3,4,5)*	*SCIP PUMPAGE (6)*	*EST. OTHER PUMPAGE*	*EST. TOTAL GRIC PUMPAGE*
1978	32,800	5.75	188,600	17,400	36,300	134,900	171,200
1979	37,600	5.75	216,200	58,200	23,000	135,800	191,800
1980	41,900	5.75	240,900	57,300	35,600	148,000	183,600
1981	45,800	5.75	263,300	22,400	47,900	193,000	240,900
1982	39,800	5.75	228,900	19,800	43,000	166,100	209,100
1983	30,000	5.75	172,500	26,100	38,600	107,800	146,400
1984	39,000	5.75	224,300	79,400	35,800	109,100	144,900
1985	30,400	5.75	174,800	79,200	30,000	65,600	95,600
1986	29,700	5.75	170,800	73,000	40,900	56,900	97,800
1987	33,300	5.75	191,500	108,000	36,800	46,700	83,500
1988	36,400	5.75	209,300	112,000	36,800	60,500	97,300

Notes:

1) Cropped acreage includes all farmed acreage on GRIC. Source: BIA crop reports (1978-1988). 1985 cropped acreage increased by 7000 acres to account for non-SCIP acreage which was omitted from BIA report.

2) Effective Consumptive Use. Source: ADWR (1991).

3) SCIP surface water to land equals total SCIP water to land minus SCIP Indian pumpage. Source: SCIP (1978-1987).

4) Other surface water - SRP Gila Drain discharge. Source: SRP (1990b).

5) Other surface water - City of Mesa Lone Butte Treatment Plant discharge. Source: City of Mesa (1990).

6) SCIP Indian pumpage from annual individual well pumpage summaries. Source: SCIP (1978-1987). 1988 annual pumpage estimated from 1987 data.

D. Evapotranspiration

Evapotranspiration from phreatophytes represents the only other significant outflow from the modern groundwater system. Evapotranspiration occurs from phreatophyte growth along the Salt and Gila Rivers. Substantial changes have occurred in the riparian communities since the predevelopment era. Indigenous species of plants have been replaced. The dense growth of tamarisk shrubs and trees that now characterizes the riparian environments of the major rivers of central Arizona did not develop until the late 1920s (Robinson, 1965). The present area occupied by phreatophytes is shown in Figure 21. Several factors control the location and density of phreatophytes along the Salt and Gila Rivers. The primary factors controlling growth are depth to water and flood events.

The single most important factor controlling phreatophyte growth is depth to water (Graf, 1980). Phreatophytes sustain growth where the depth to water is less than 20 to 30 feet below land surface. This is evident along various reaches of the Salt and Gila Rivers. Along the Gila River, downstream from the confluence with the Salt, the depth to water is generally less than 20 to 30 feet and phreatophtyes are prolific and dense in some areas. However, phreatophyte growth is essentially non-existent along the Salt River upstream of the City of Phoenix 23rd Avenue Waste Water Treatment Plant. This lack of growth correlates with the fact that the depth to water is greater than 30 feet in that area.

Flood events have effected the distribution of phreatophytes along the Salt and Gila Rivers throughout time. The major flood flows of 1978, 1979, 1980 and 1983 essentially cleaned the Salt River channel clear of any phreatophytes. According to Graf (1980), "Floodflows are probably important in the maintenance as well as the destruction of phreatophytes. Floods clear large areas of other growth and deposit moist silt and sand accumulations that make ideal seedbeds for the establishment of new phreatophyte communities."

The 1978 and 1987 phreatophyte distribution and density was estimated from Landsat image analysis. These years were selected as being representative of phreatophyte conditions before and after the flood events of the late 1970s and early 1980s, and also due to the availability of Landsat digital images. The area covered by the Landsat images included the entire Gila and Santa Cruz River systems within the study area, and the Salt River downstream from the City of Phoenix 23rd Avenue Waste Water Treatment Plant. Phreatophyte acreage per section was estimated from the Landsat digital images. Field observations were used to correlate phreatophyte type and density with digital image color.

Five separate phreatophyte density-type categories were defined on the basis of the correlation between digital image color and field observations, the categories include: bare, sparse, medium, dense, and cropped areas. The sparse category contained a total phreatophyte density per acre of about 30 percent; with a division in coverage of 20 percent tamarisk, and 80 percent mesquite. The medium category contained a total phreatophyte density per acre of about 50 percent; with a division in coverage of 50 percent tamarisk, and 50 percent mesquite. The dense category contained a total phreatophyte density per acre of about 80 percent: with a division in coverage of 80 percent tamarisk, and 20 percent mesquite. The Blaney-Criddle method was used calculate consumptive use factors for tamarisk and mesquite of 8.7 feet per year per acre and 3.9 feet per year per acre, respectively, assuming 100 percent density (Gatewood, and others, 1950). A combined consumptive use factor was calculated for each category based on the density and relative percentage of tamarisk and mesquite. The calculated consumptive use factors were: sparse - 1.46 ft per year per acre, medium - 3.15 feet per year per acre, dense - 6.19 feet per year per acre. Maximum water use per section was calculated based on the estimates phreatophyte acreage and density. The total estimated phreatophyte acreage for 1978 and 1987 was about 26,000 acres. The estimated maximum total evapotranspiration loss was 90,000 acre-feet for 1978, and 83,000 acre-feet for 1987.

E. Conceptual Groundwater Budget -- 1978-1988

A groundwater budget for the period 1978-1988 has been developed for the SRV study area (Table 24). The total inflows for the period were approximately 13.5 million acre-feet. The total outflows were approximately 14.0 million acre-feet. The estimated decrease in the volume of groundwater in storage was 0.5 million acre-feet.

Table 24

Conceptual Groundwater Budget For The SRV Study Area 1978-1988

(Figures Rounded to Nearest 1000 Acre-Feet)

1978-1988 Inflows											
	1978	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*
Underflow	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000
Ag Irrigation Recharge	672,000	688,000	706,000	726,000	581,000	441,000	561,000	464,000	415,000	450,000	495,000
Urban Irrigation Recharge	58,000	58,000	58,000	58,000	58,000	58,000	58,000	58,000	58,000	58,000	58,000
Canal Recharge	241,000	263,000	256,000	300,000	245,000	200,000	207,000	213,000	184,000	172,000	157,000
Artificial Lake Recharge	7,000	7,000	7,000	7,000	7,000	7,000	11,000	13,000	13,000	13,000	13,000
Effluent Recharge	40,000	45,000	47,000	49,000	43,000	34,000	26,000	24,000	40,000	45,000	46,000
Major Drainage Recharge	495,000	636,000	774,000	3,000	48,000	776,000	161,000	317,000	29,000	31,000	22,000
Mountain-Front Recharge	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Ephemeral Stream Recharge	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
Totals	1,553,000	1,737,000	1,888,000	1,183,000	1,022,000	1,556,000	1,064,000	1,129,000	779,000	809,000	831,000

1978-1988 Outflows											
	1978	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*
Underflow	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Pumpage	1,230,000	1,145,000	1,236,000	1,814,000	1,269,000	799,000	1,330,000	1,014,000	991,000	934,000	1,000,000
Evapotranspiration	90,000	90,000	90,000	90,000	90,000	83,000	83,000	83,000	83,000	83,000	83,000
Totals	1,350,000	1,265,000	1,356,000	1,934,000	1,389,000	912,000	1,443,000	1,127,000	1,104,000	1,047,000	1,113,000

Total Estimated Inflow 1978-1988 = 13,551,000 Acre-Feet

Total Estimated Outflow 1978-1988 = 14,040,000 Acre-Feet

Total Inflows - Total Outflows 1978-1988 = -489,000 Acre-feet

CHAPTER SIX. SUMMARY AND RECOMMENDATIONS

I. SUMMARY

This report documents an extensive effort toward analyzing and quantifying the groundwater flow system of the SRV study area. The SRV study area encompasses the heaviest water use area of the state and includes the ESRV and WSRV sub-basins of the Phoenix AMA, and the northern portion of the Maricopa-Stanfield (MST) sub-basin of the Pinal AMA. The data collection and analysis effort has included detailed examination of geologic, hydrologic, and water use data. Much of the data discussed in this report is available in PC compatible database formats from the ADWR Modeling Section.

The detailed analysis of the data has made it possible to formulate estimates of all the major inflow and outflow components of the predevelopment and modern groundwater systems. A groundwater budget for the period 1978-1988 has been developed for the SRV study area. The total inflows for the period were approximately 13.5 million acre-feet, and the total outflows were approximately 14.0 million acre-feet. The estimated decrease in the volume of groundwater in storage was 0.5 million acre-feet. These estimates have been used to provide initial groundwater model inputs. It should be recognized that many of the initial model estimates, particularly those of groundwater recharge may be reduced during the model calibration.

The next phase of the modeling effort is the final calibration and sensitivity testing of the groundwater model. This phase is well underway. The details of the model construction and calibration will be released in a Phase II report sometime in 1993.

II. RECOMMENDATIONS

Several data deficiencies were recognized during the data collection and analysis phase of this project. Major data deficiencies included: 1) hydraulic conductivity data, 2) aquifer storage property data, 3) unit-specific waterlevel data, 4) streamgage data. The importance of these data cannot be overemphasized. The data comprise fundamental model inputs which significantly impact the accuracy of the groundwater model. The following recommendations are suggested to improve these data deficiencies.

1) Hydraulic conductivity data were found to be lacking in most parts of the study area. Aquifer test data are by far the best type of information available for estimating hydraulic conductivities. For this reason it is recommended that the ADWR engage in a long-term program to collect and analyze this type of data. One way that this recommendation can be implemented is to enact by rule or statute a requirement that the results of any hydrologic testing be reported to the Department. The data could be transmitted directly to the Hydrology Division where it could be analyzed and entered into an aquifer test database. Additionally, the Department should only accept completely filled out well registrations, which include well logs and other well data. The data collected would undoubtedly improve our present knowledge of hydraulic conductivities.

2) Aquifer storage property data were also found to be lacking in most parts of the study area. Aquifer tests provide estimates of storativities. However, most tests are generally too short in duration to completely drain pore space, and therefore provide unreliable values for specific yield. In addition, the storage properties of compressible sediments (specific storage and storage coefficient) are effected by aquifer system compaction in areas of extensive groundwater

withdrawals. For these reasons it is recommended that alternative methods of estimating aquifer storage properties be studied and considered for future use in specific locations.

Two methods which should receive further study and evaluation are gravity change measurements for specific yield, and vertical extensometers for estimating the storage properties of compressible sediments. Currently the USGS and the City of Tucson conduct gravity change and extensometer studies in the Tucson and Avra Valley areas. Although these studies are somewhat experimental in nature the studies should provide much valuable information concerning the feasibility of applying the methodologies to other areas.

If the studies prove successful the methodologies should be considered for pilot implementation in strategic areas of the SRV. The areas which should be considered include: 1) underground storage and recovery sites, 2) major drainages, and 3) areas of significant groundwater depression and land subsidence. The storage information derived from studies at such sites would be useful to improve the groundwater model, quantify groundwater storage changes, and provide estimates of land subsidence potential at important locations throughout the area.

3) Unit-specific water level information were another data input which was found lacking during the data collection and analysis phase of this study. The water level data collected for 1983 was relatively comprehensive due to the large number of water level measurements which were made. However, the 1988 data were extremely meager and few waterlevels were measured from MAU and LAU wells.

Due to the necessity of obtaining representative water levels from all units in each year it is recommended that the ADWR Phoenix AMA index line be expanded and revised to provide a more representative sample of both the vertical and areal distribution of water levels.

4) Streamgage data were found to be significantly lacking during the data collection phase. The analysis of stream channel infiltration was made much more difficult and questionable due to this shortcoming. Examination of the volume of releases from the Granite Reef and Ashurst-Hayden Dams (Tables 17 and 19) during the period 1978-1988 reveals that flood flows on these rivers represent a potentially significant recharge source which needs to be better quantified, both for modeling purposes and for regulatory purposes.

Accurate assessment of stream channel recharge is important from a regulatory point of view because of the statutory requirement that the Phoenix AMA achieve safe yield by the year 2025. It is also important to accurately assess recharge due to the possible creation of the Phoenix AMA Replenishment District. Both the safe yield mandate and the Replenishment District operational rules require an assessment of recharge to the aquifer (both natural and incidental).

Since stream channel recharge from flood flows represents a potentially important component of inflow to the groundwater system it is recommended that the current number of stream gages in the SRV study area be increased. The new gages should be strategically located in order to better quantify infiltration along several reaches of the major drainages in the area. New technology and telemetry equipment would make the cost of an expanded network affordable. It might also be possible to share the cost of installation and operation of the system with the municipalities or other agencies.

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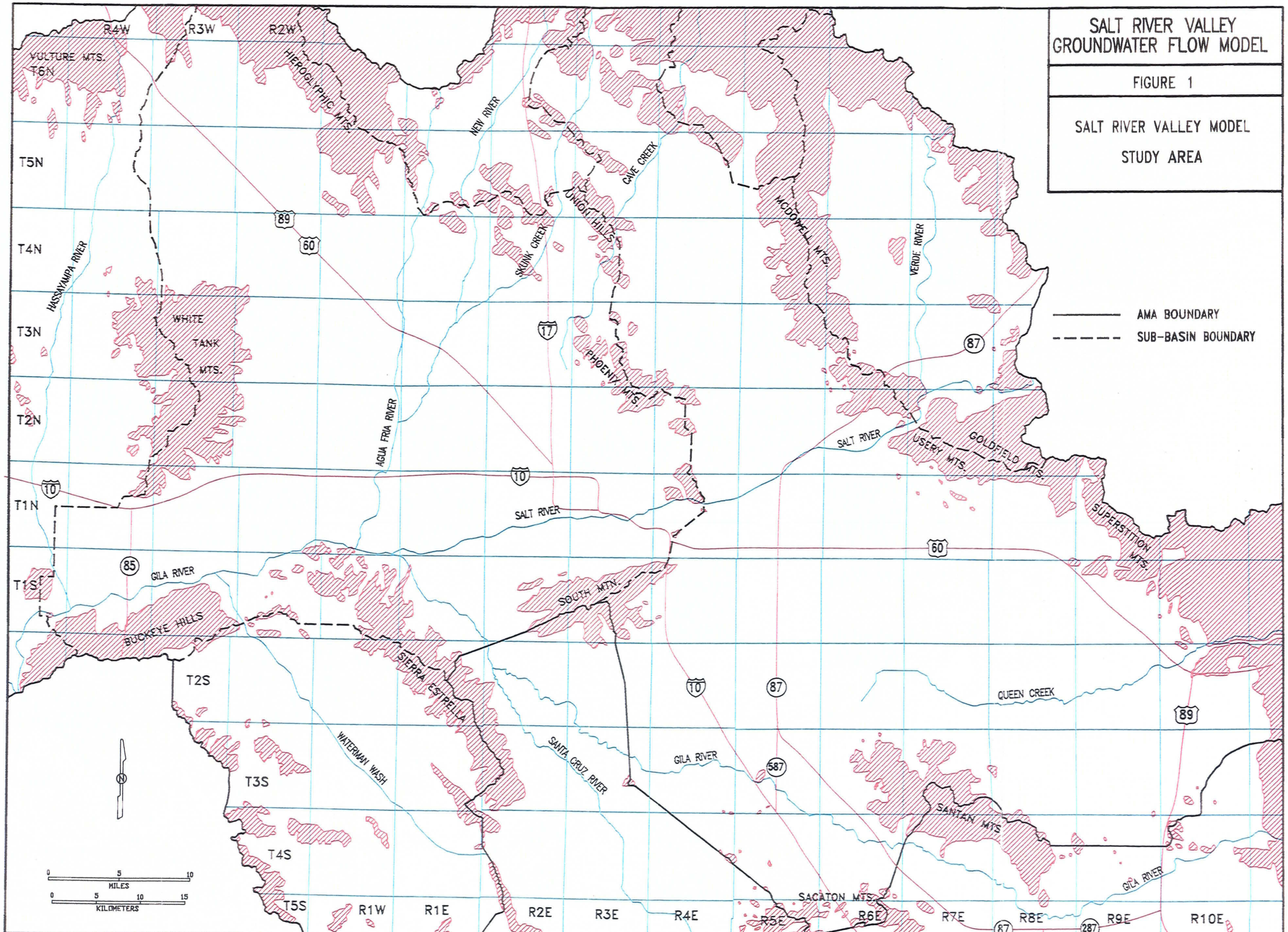
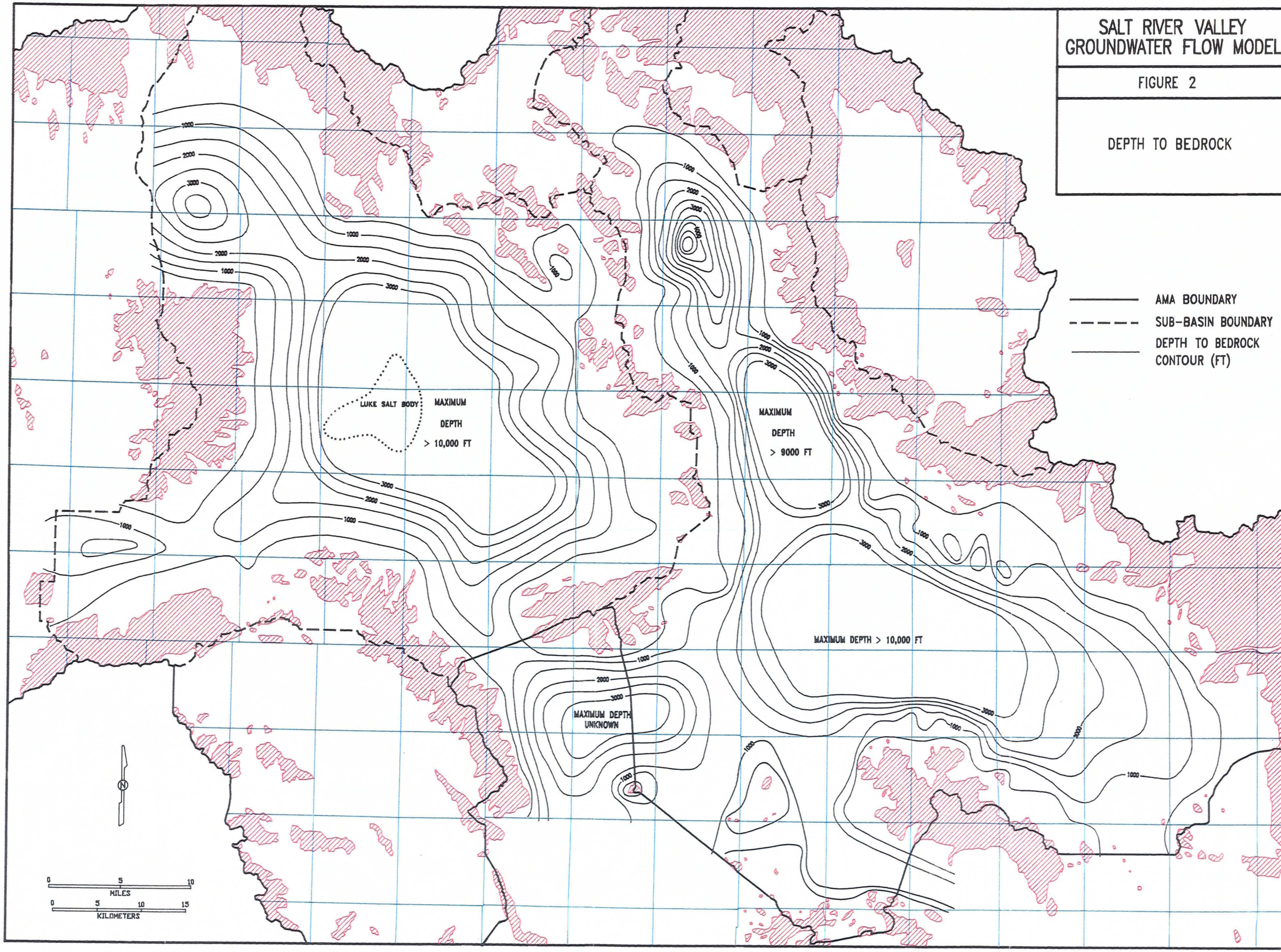
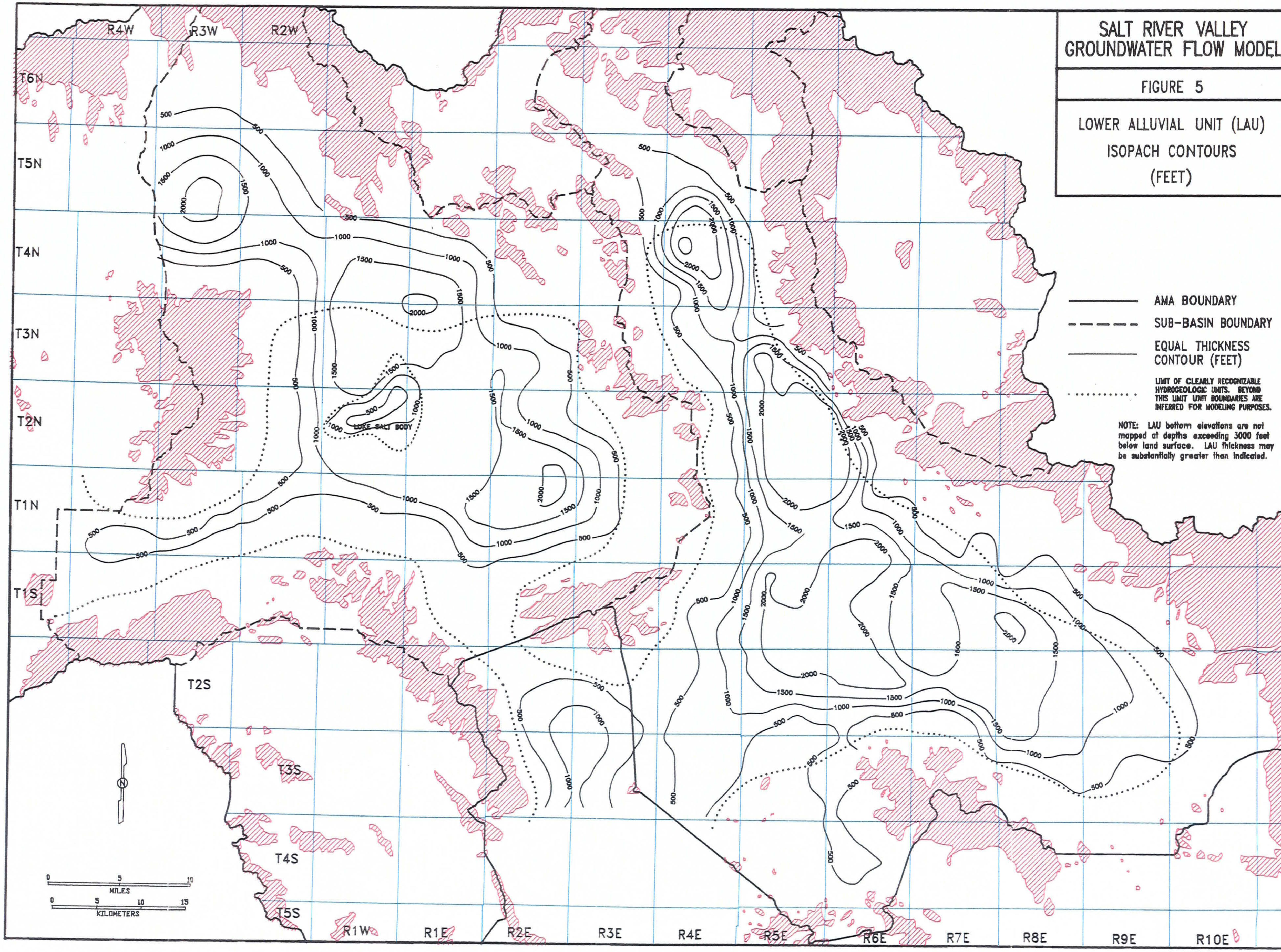
Appendix I

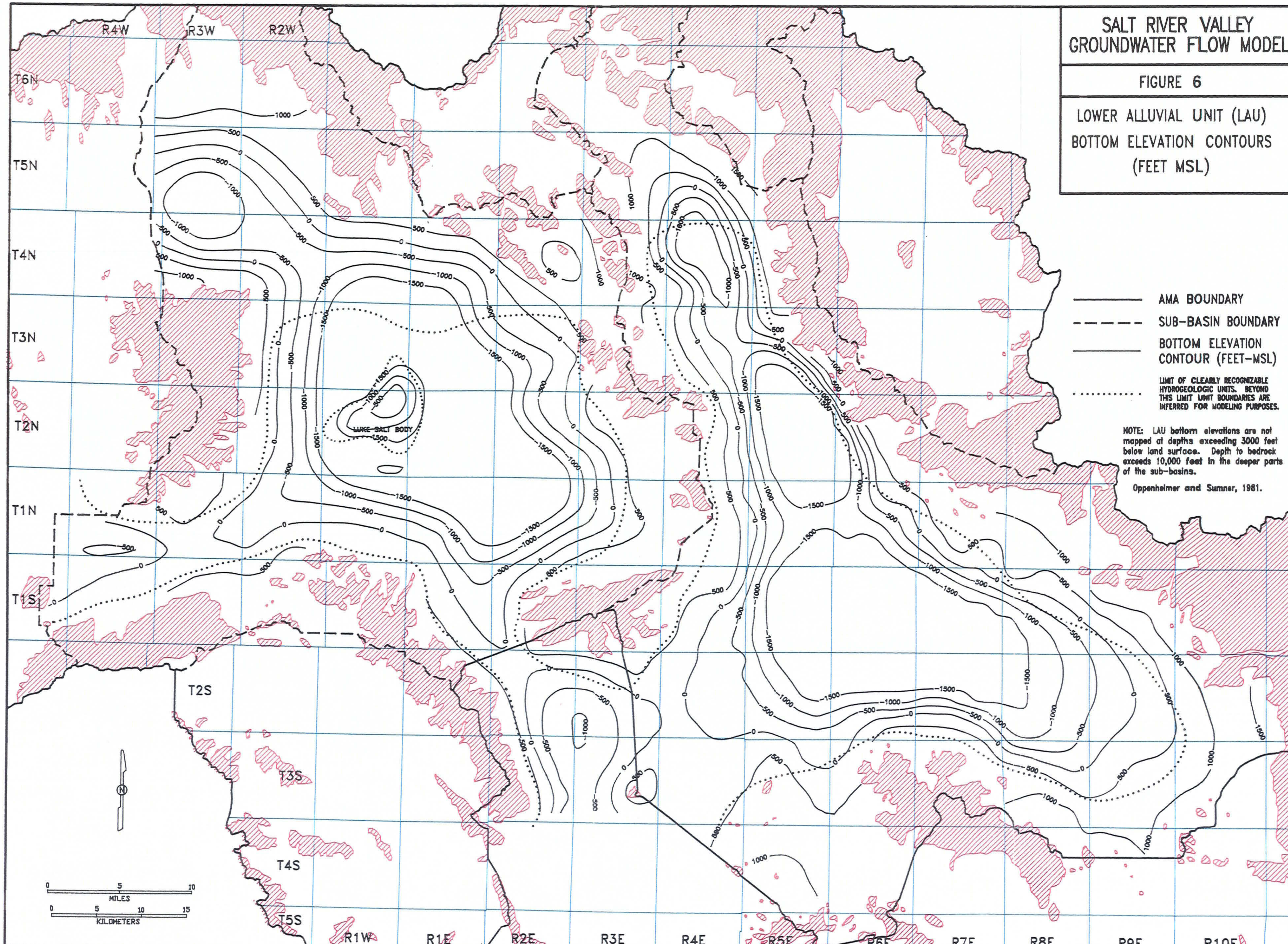
Figures


SALT RIVER VALLEY GROUNDWATER FLOW MODEL
FIGURE 1
SALT RIVER VALLEY MODEL STUDY AREA
AMA BOUNDARY
SUB-BASIN BOUNDARY
VULTURE MTS.
HIEROGLYPHIC MTS.
WHITE TANK MTS.
HASSAYAMPA RIVER
AGUA FRIA RIVER
NEW RIVER
CAVE CREEK
SKUNK CREEK
UNION HILLS
PHOENIX MTS.
MCDOWELL MTS.
VERDE RIVER
SALT RIVER
USERY MTS.
GOLDFIELD MTS.
SUPERSTITION MTS.
GILA RIVER
BUCKEYE HILLS
SOUTH MTN.
SIERRA ESTRELLA
WATERMAN WASH
SANTA CRUZ RIVER
QUEEN CREEK
SANTAN MTS.
SACATON MTS.
R4W R3W R2W R1W R1E R2E R3E R4E R5E R6E R7E R8E R9E R10E
T6N T5N T4N T3N T2N T1N T1S T2S T3S T4S T5S
89 60 17 87 10 85 587 287
MILES
0 5 10
KILOMETERS
0 5 10 15
N

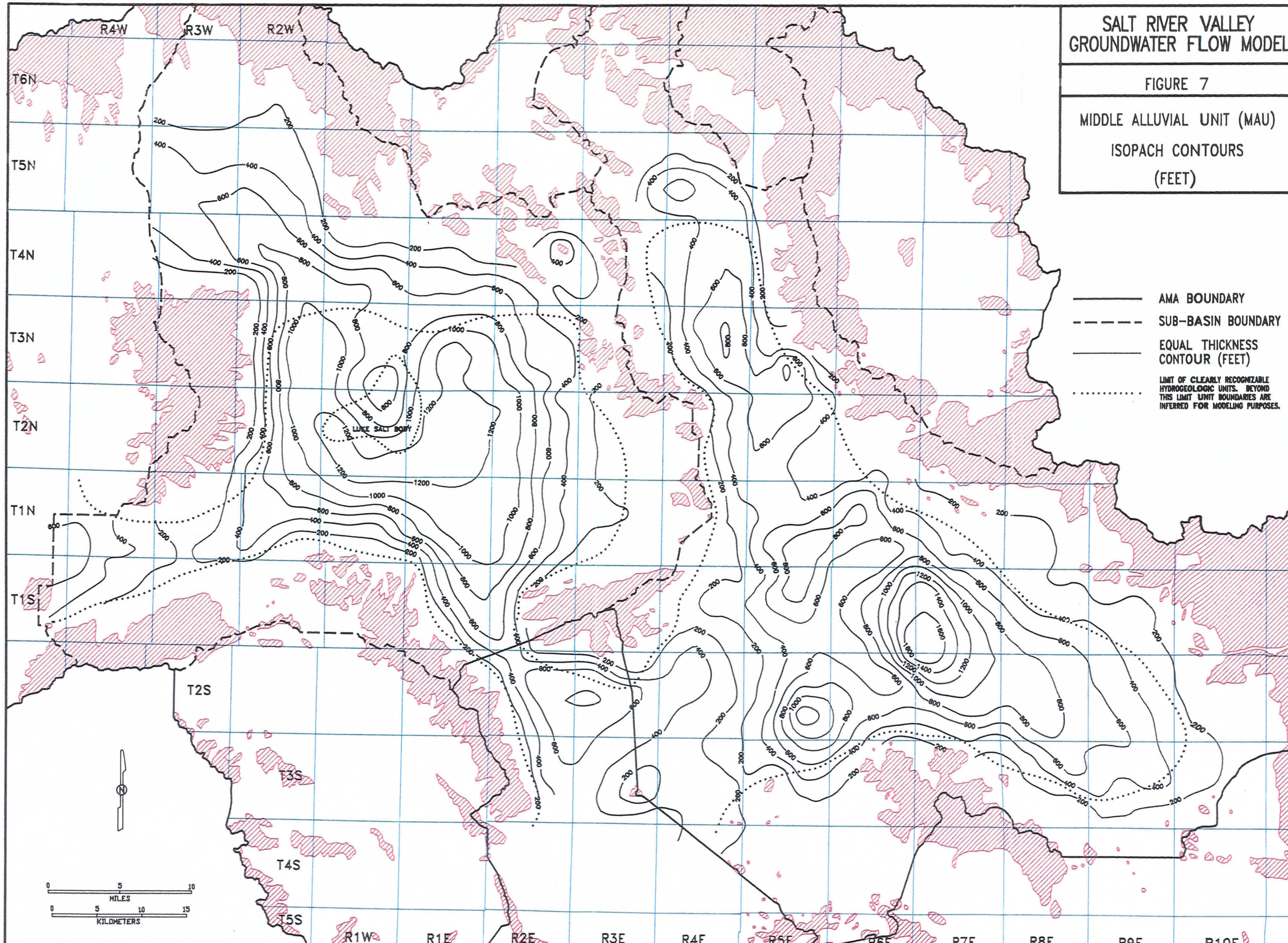


SALT RIVER VALLEY
GROUNDWATER FLOW MODEL
FIGURE 2
DEPTH TO BEDROCK
AMA BOUNDARY
SUB-BASIN BOUNDARY
DEPTH TO BEDROCK CONTOUR (FT)
LUKE SALT BODY
MAXIMUM DEPTH > 10,000 FT
MAXIMUM DEPTH > 9000 FT
MAXIMUM DEPTH > 10,000 FT
MAXIMUM DEPTH UNKNOWN
1000
2000
3000
MILES
KILOMETERS
0
5
10
15

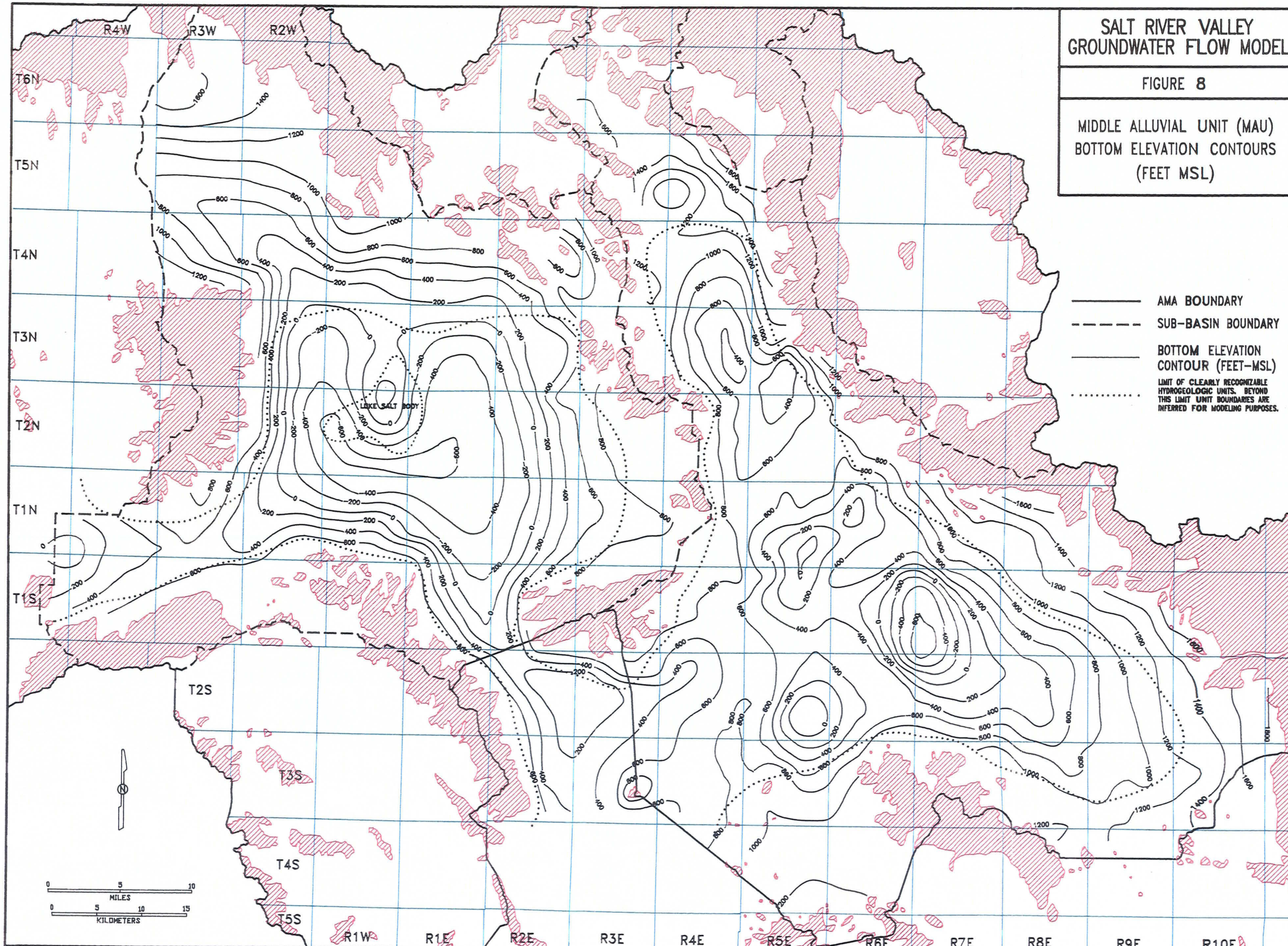

SALT RIVER VALLEY GROUNDWATER FLOW MODEL
FIGURE 5
LOWER ALLUVIAL UNIT (LAU) ISOPACH CONTOURS (FEET)
AMA BOUNDARY
SUB-BASIN BOUNDARY
EQUAL THICKNESS CONTOUR (FEET)
LIMIT OF CLEARLY RECOGNIZABLE HYDROGEOLOGIC UNITS. BEYOND THIS LIMIT UNIT BOUNDARIES ARE INFERRED FOR MODELING PURPOSES.
NOTE: LAU bottom elevations are not mapped at depths exceeding 3000 feet below land surface. LAU thickness may be substantially greater than indicated.
LUKE SALT BODY
MILES
KILOMETERS
R4W
R3W
R2W
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S

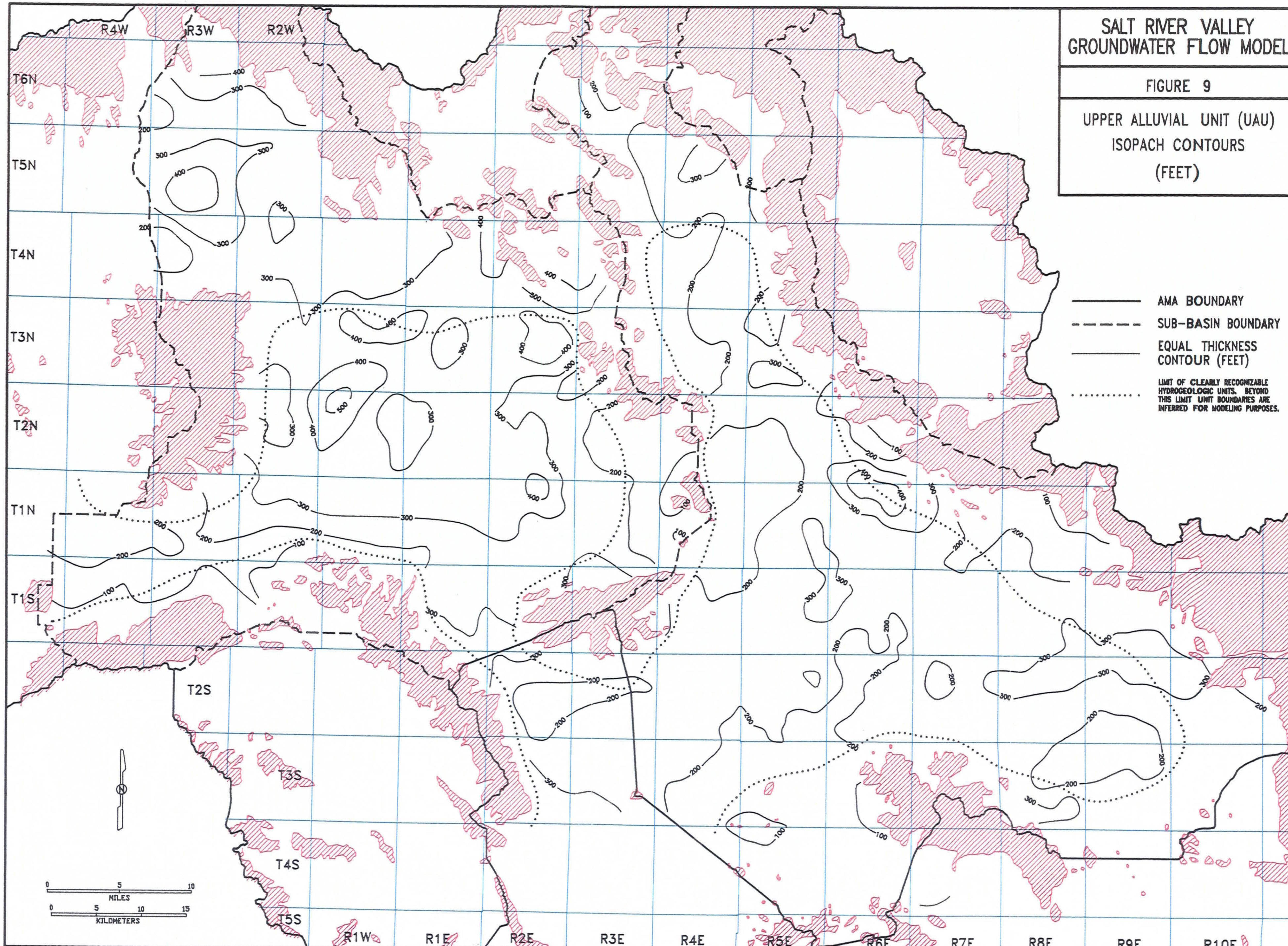


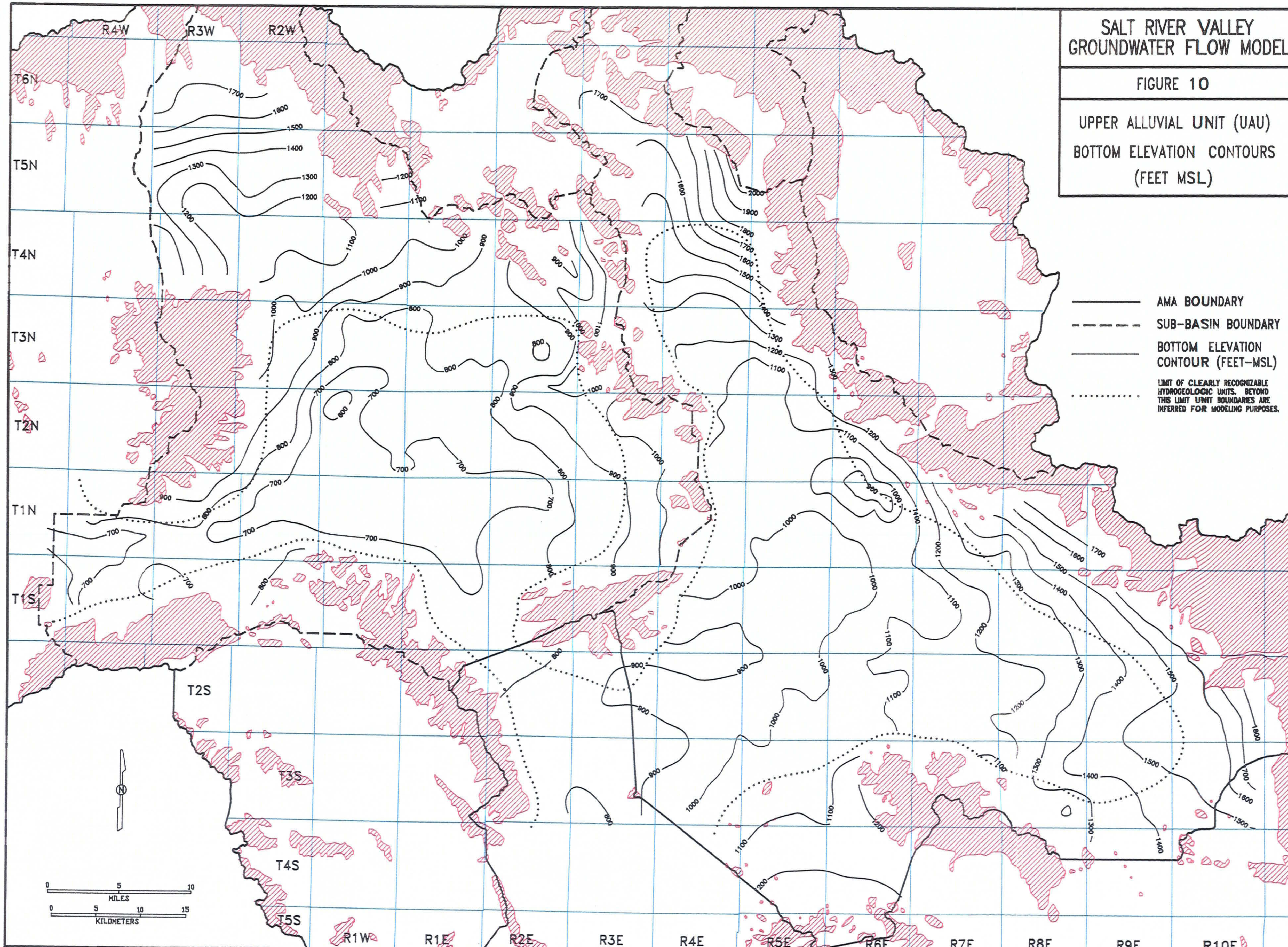
SALT RIVER VALLEY
GROUNDWATER FLOW MODEL
FIGURE 6
LOWER ALLUVIAL UNIT (LAU)
BOTTOM ELEVATION CONTOURS
(FEET MSL)
AMA BOUNDARY
SUB-BASIN BOUNDARY
BOTTOM ELEVATION CONTOUR (FEET-MSL)
LIMIT OF CLEARLY RECOGNIZABLE HYDROGEOLOGIC UNITS. BEYOND THIS LIMIT UNIT BOUNDARIES ARE INFERRED FOR MODELING PURPOSES.
NOTE: LAU bottom elevations are not mapped at depths exceeding 3000 feet below land surface. Depth to bedrock exceeds 10,000 feet in the deeper parts of the sub-basins.
Oppenheimer and Sumner, 1981.
LUKE SALT BODY
MILES
KILOMETERS
R4W
R3W
R2W
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S



SALT RIVER VALLEY GROUNDWATER FLOW MODEL
FIGURE 7
MIDDLE ALLUVIAL UNIT (MAU)
ISOPACH CONTOURS
(FEET)
AMA BOUNDARY
SUB-BASIN BOUNDARY
EQUAL THICKNESS CONTOUR (FEET)
LIMIT OF CLEARLY RECOGNIZABLE HYDROGEOLOGIC UNITS. BEYOND THIS LIMIT UNIT BOUNDARIES ARE INFERRED FOR MODELING PURPOSES.
LUKE SALT BODY
MILES
KILOMETERS
R4W
R3W
R2W
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S


SALT RIVER VALLEY GROUNDWATER FLOW MODEL
FIGURE 8
MIDDLE ALLUVIAL UNIT (MAU) BOTTOM ELEVATION CONTOURS (FEET MSL)
AMA BOUNDARY
SUB-BASIN BOUNDARY
BOTTOM ELEVATION CONTOUR (FEET-MSL)
LIMIT OF CLEARLY RECOGNIZABLE HYDROGEOLOGIC UNITS. BEYOND THIS LIMIT UNIT BOUNDARIES ARE INFERRED FOR MODELING PURPOSES.
LUKE SALT BODY
MILES
KILOMETERS
R4W
R3W
R2W
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S

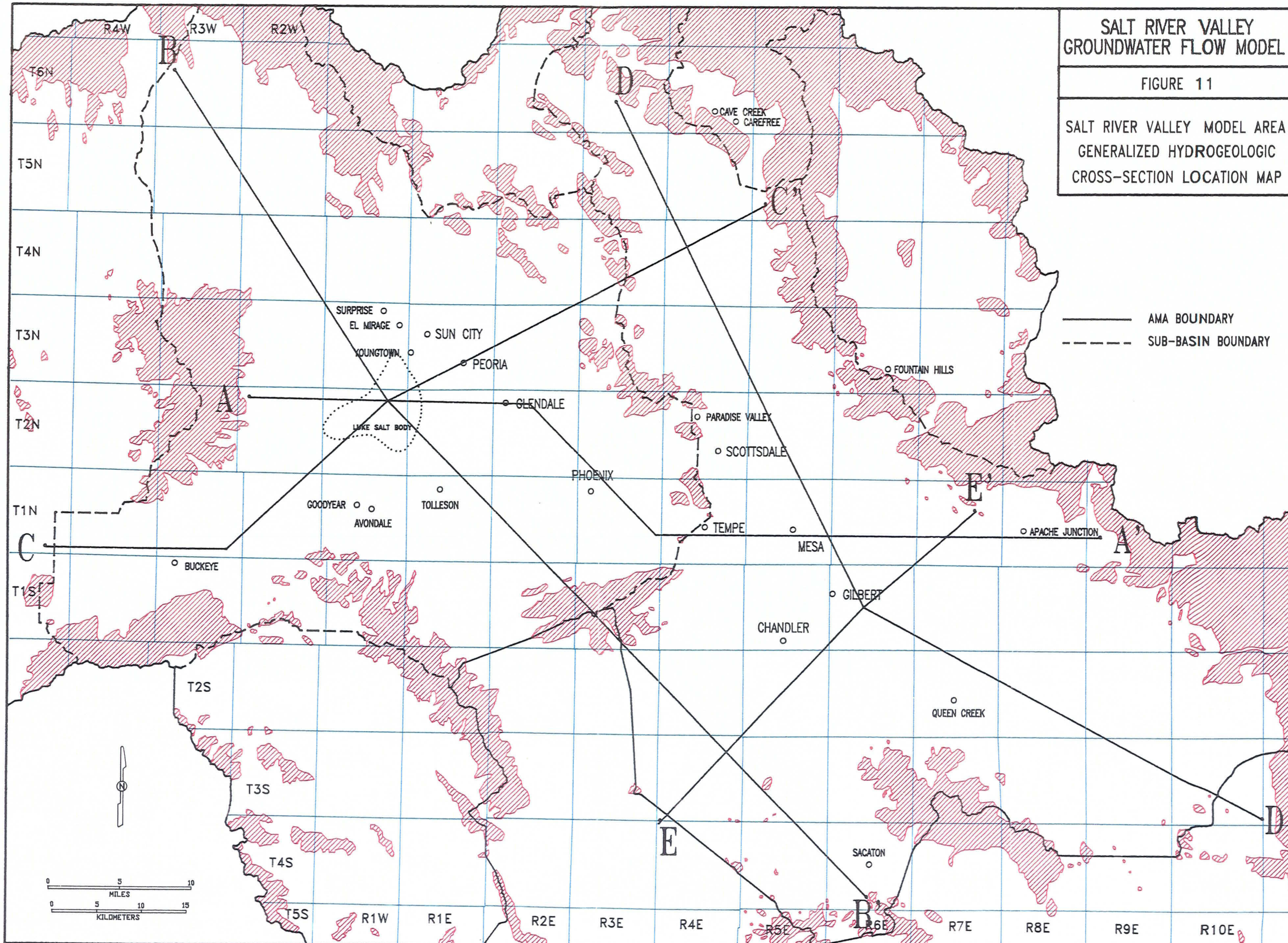

SALT RIVER VALLEY GROUNDWATER FLOW MODEL
FIGURE 9
UPPER ALLUVIAL UNIT (UAU) ISOPACH CONTOURS (FEET)
AMA BOUNDARY
SUB-BASIN BOUNDARY
EQUAL THICKNESS CONTOUR (FEET)
LIMIT OF CLEARLY RECOGNIZABLE HYDROGEOLOGIC UNITS. BEYOND THIS LIMIT UNIT BOUNDARIES ARE INFERRED FOR MODELING PURPOSES.
MILES
KILOMETERS
R4W
R3W
R2W
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S



SALT RIVER VALLEY GROUNDWATER FLOW MODEL

FIGURE 10

UPPER ALLUVIAL UNIT (UAU) BOTTOM ELEVATION CONTOURS (FEET MSL)



SALT RIVER VALLEY GROUNDWATER FLOW MODEL
FIGURE 11
SALT RIVER VALLEY MODEL AREA GENERALIZED HYDROGEOLOGIC CROSS-SECTION LOCATION MAP
AMA BOUNDARY
SUB-BASIN BOUNDARY
R4W
R3W
R2W
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
CAVE CREEK
CAREFREE
SURPRISE
EL MIRAGE
SUN CITY
YOUNGTOWN
PEORIA
GLENDALE
LUKE SALT BODY
PARADISE VALLEY
SCOTTSDALE
FOUNTAIN HILLS
PHOENIX
GOODYEAR
AVONDALE
TOLLESON
TEMPE
MESA
APACHE JUNCTION
BUCKEYE
GILBERT
CHANDLER
QUEEN CREEK
SACATON
A
A'
B
B'
C
C'
D
D'
E
E'
MILES
KILOMETERS

FIGURE 12

SALT RIVER VALLEY
GENERALIZED HYDROGEOLOGIC CROSS-SECTION

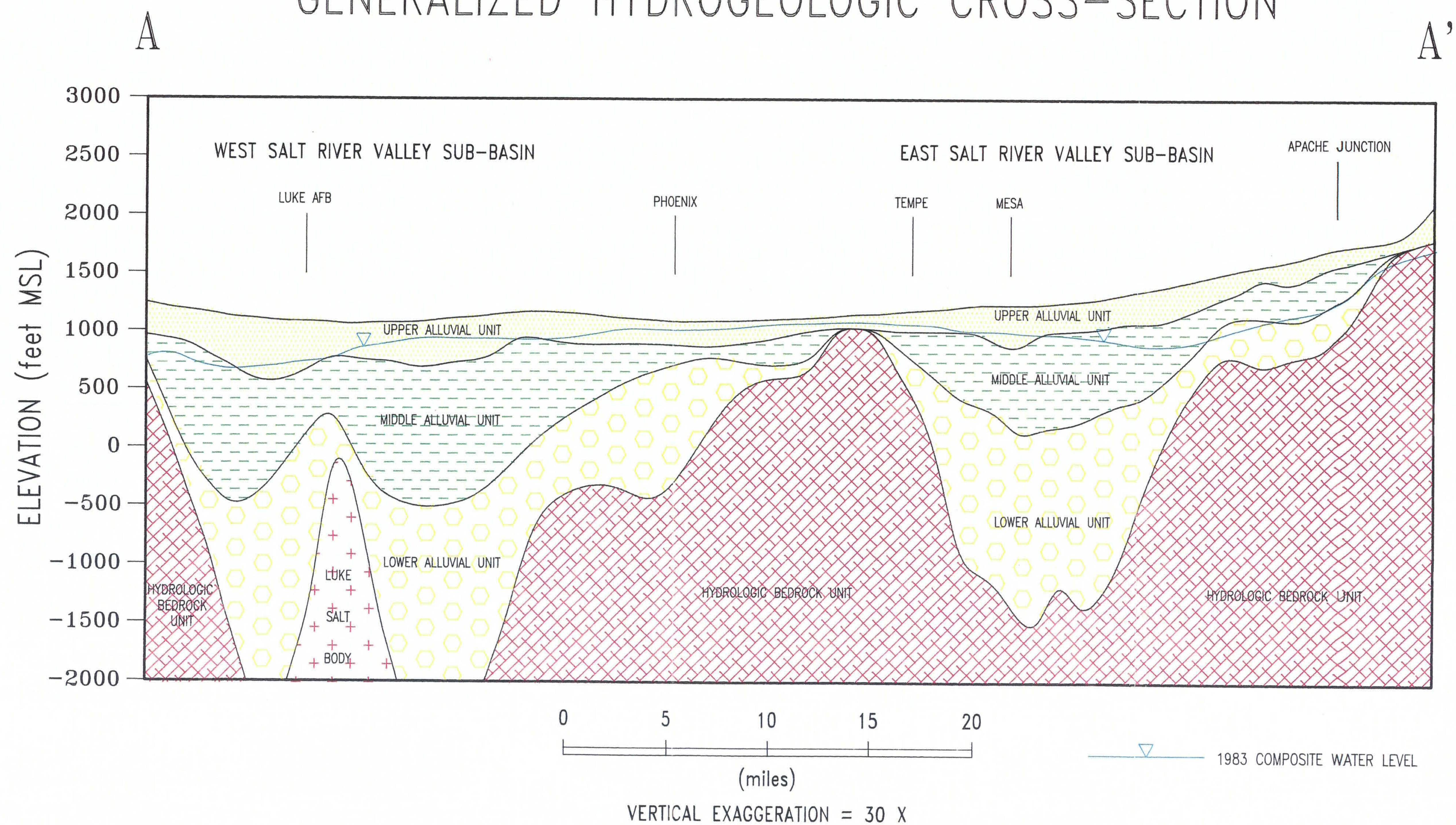


FIGURE 13

SALT RIVER VALLEY
GENERALIZED HYDROGEOLOGIC CROSS-SECTION

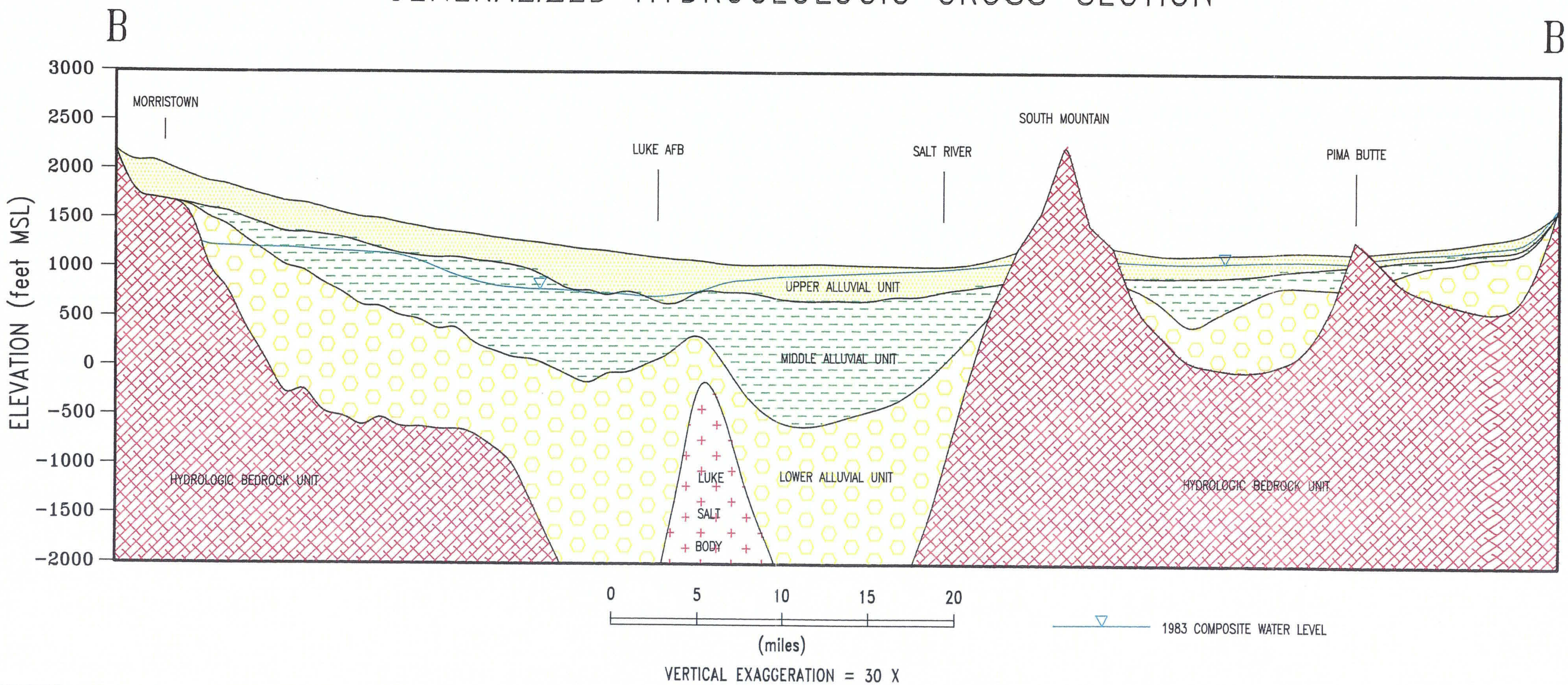
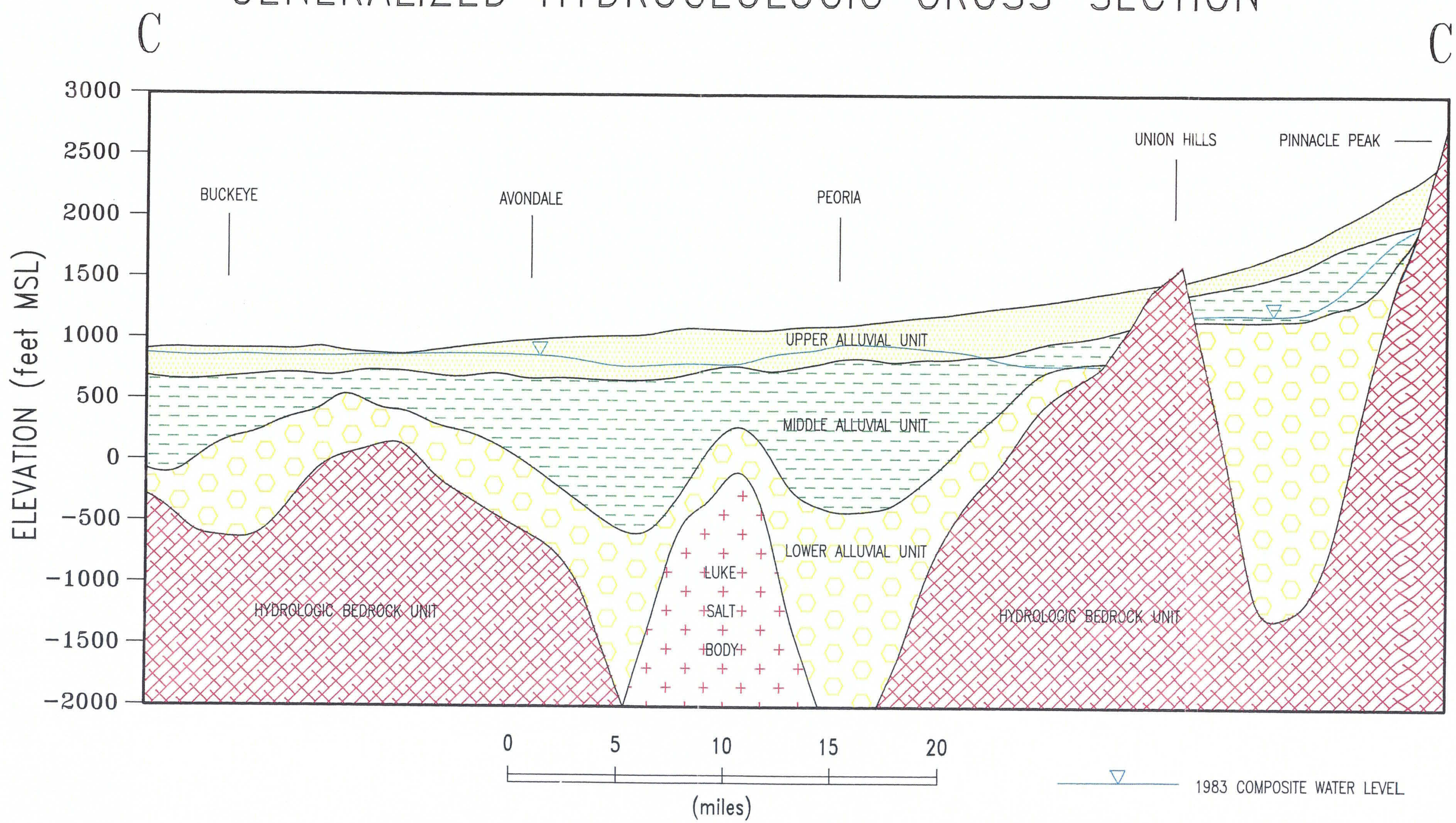


FIGURE 14

SALT RIVER VALLEY
GENERALIZED HYDROGEOLOGIC CROSS-SECTION



VERTICAL EXAGGERATION = 30 X

FIGURE 15

SALT RIVER VALLEY
GENERALIZED HYDROGEOLOGIC CROSS-SECTION

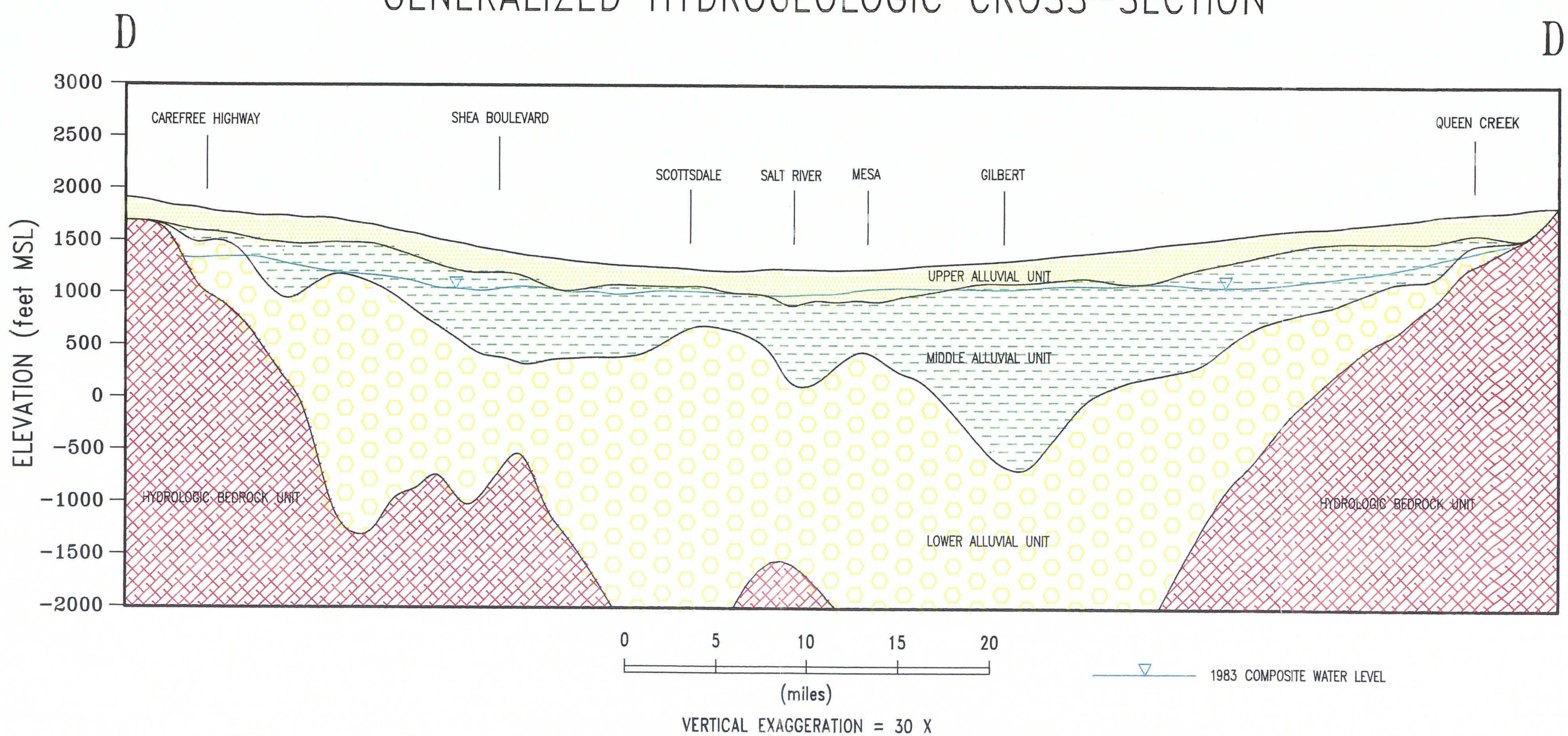
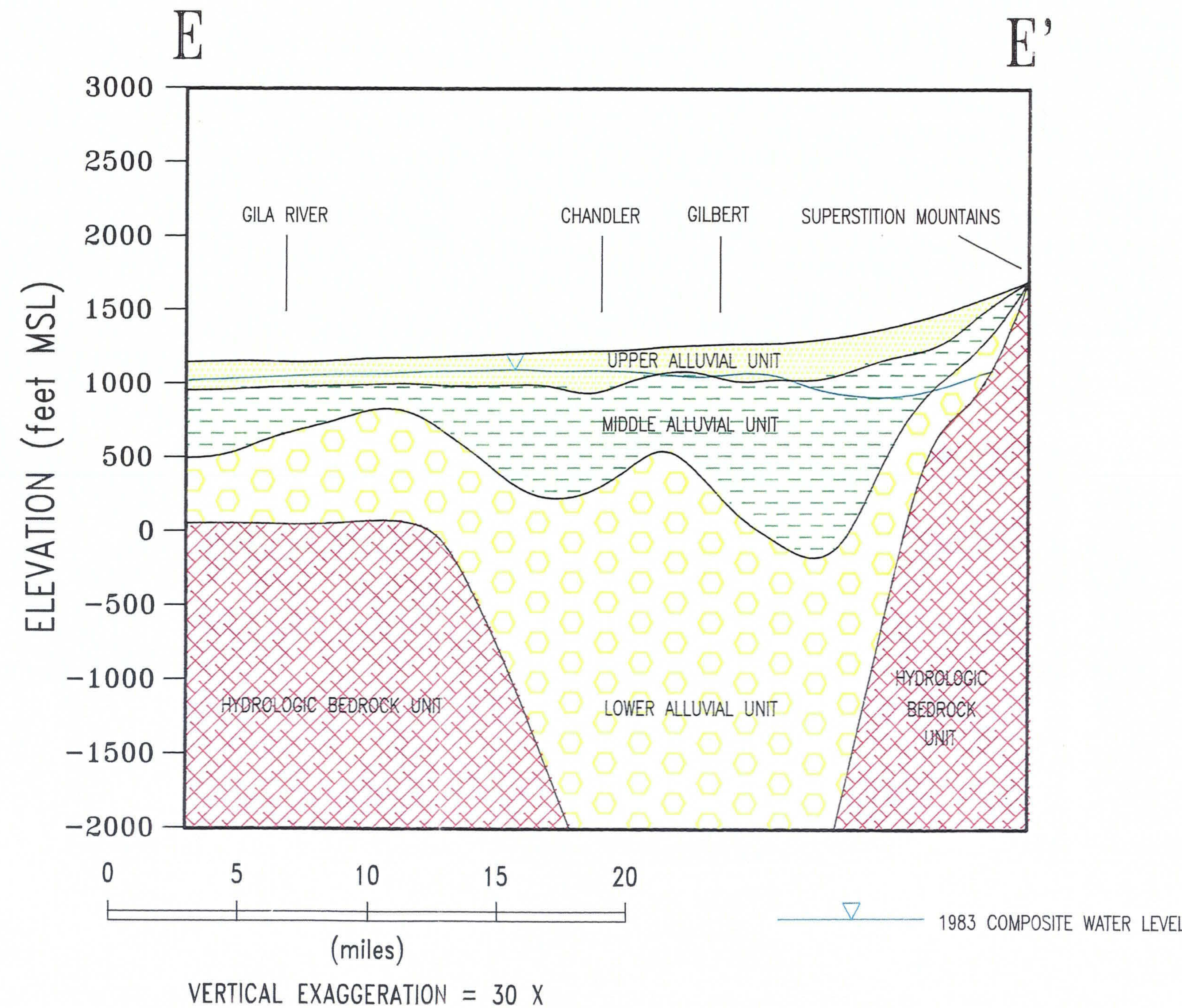


FIGURE 16

SALT RIVER VALLEY

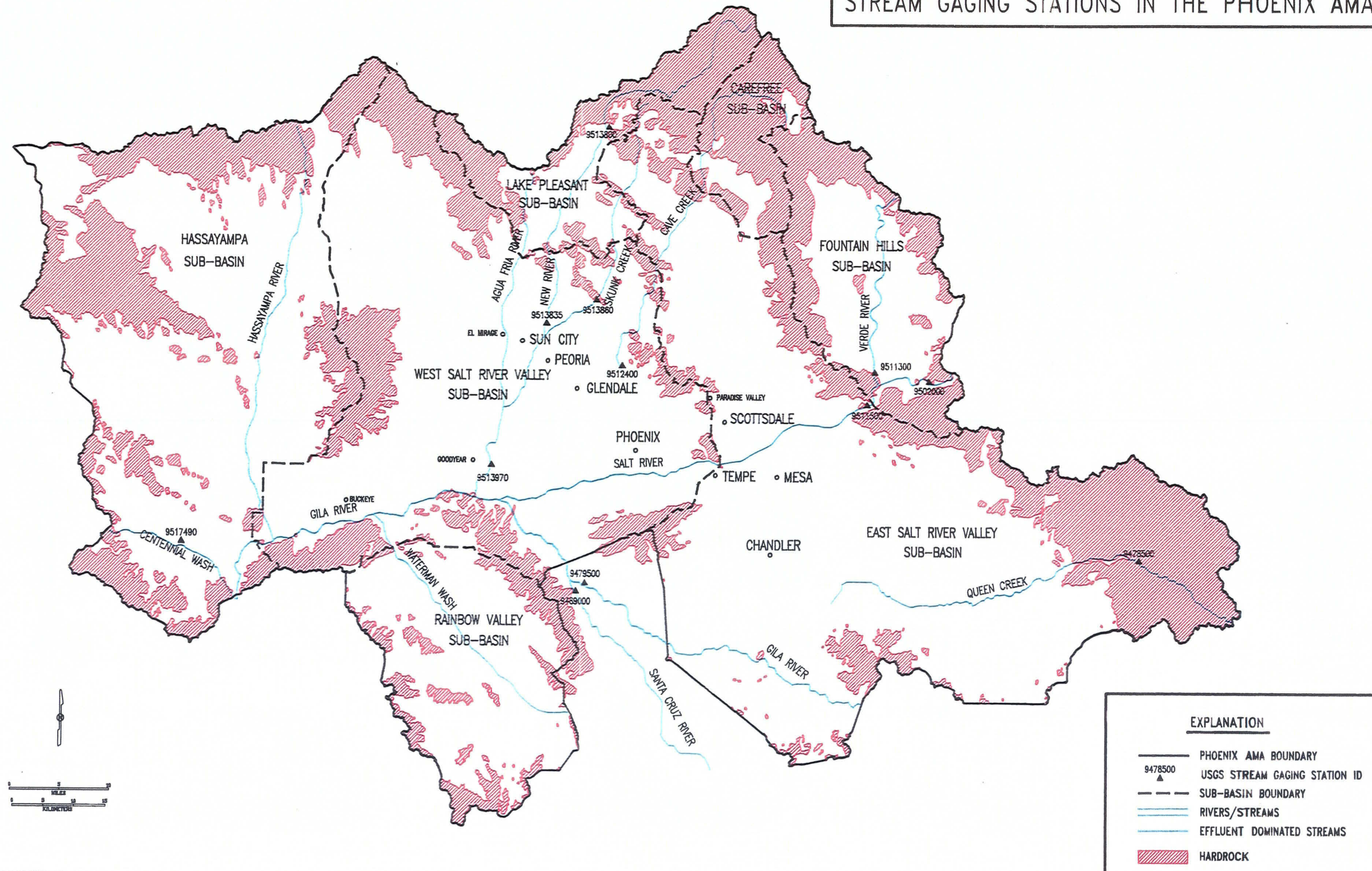
GENERALIZED HYDROGEOLOGIC CROSS-SECTION

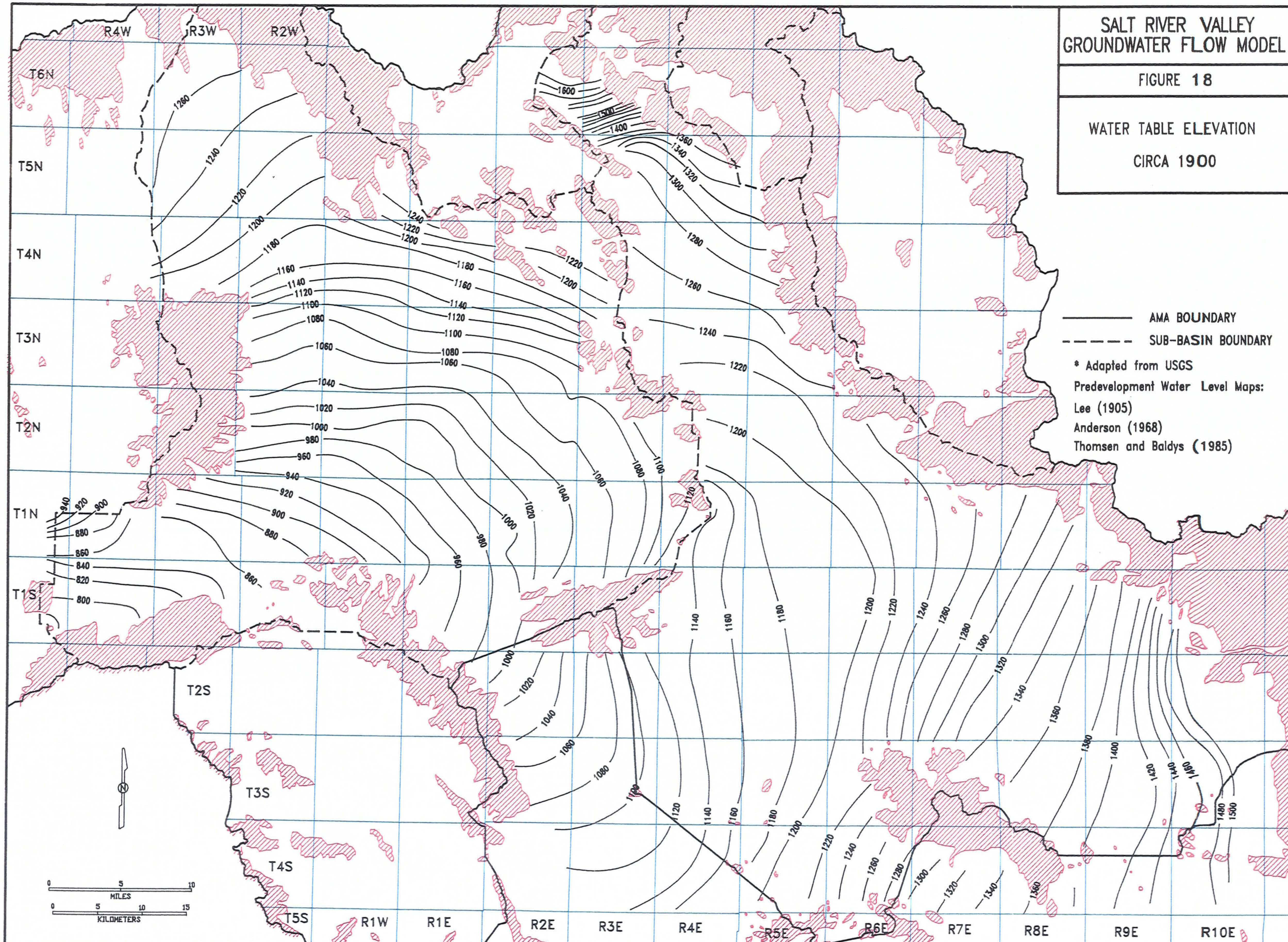


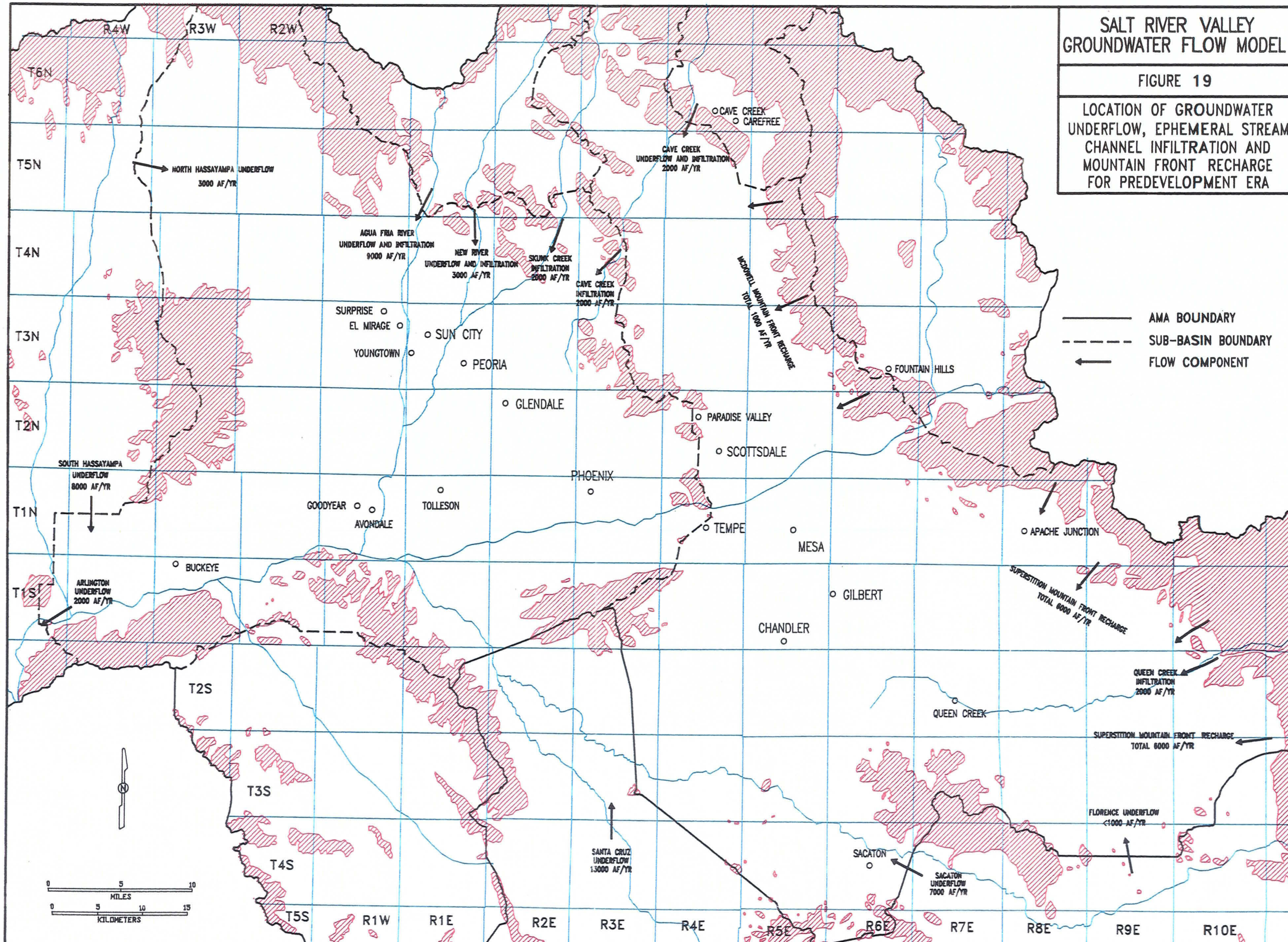
SALT RIVER VALLEY GROUNDWATER FLOW MODEL

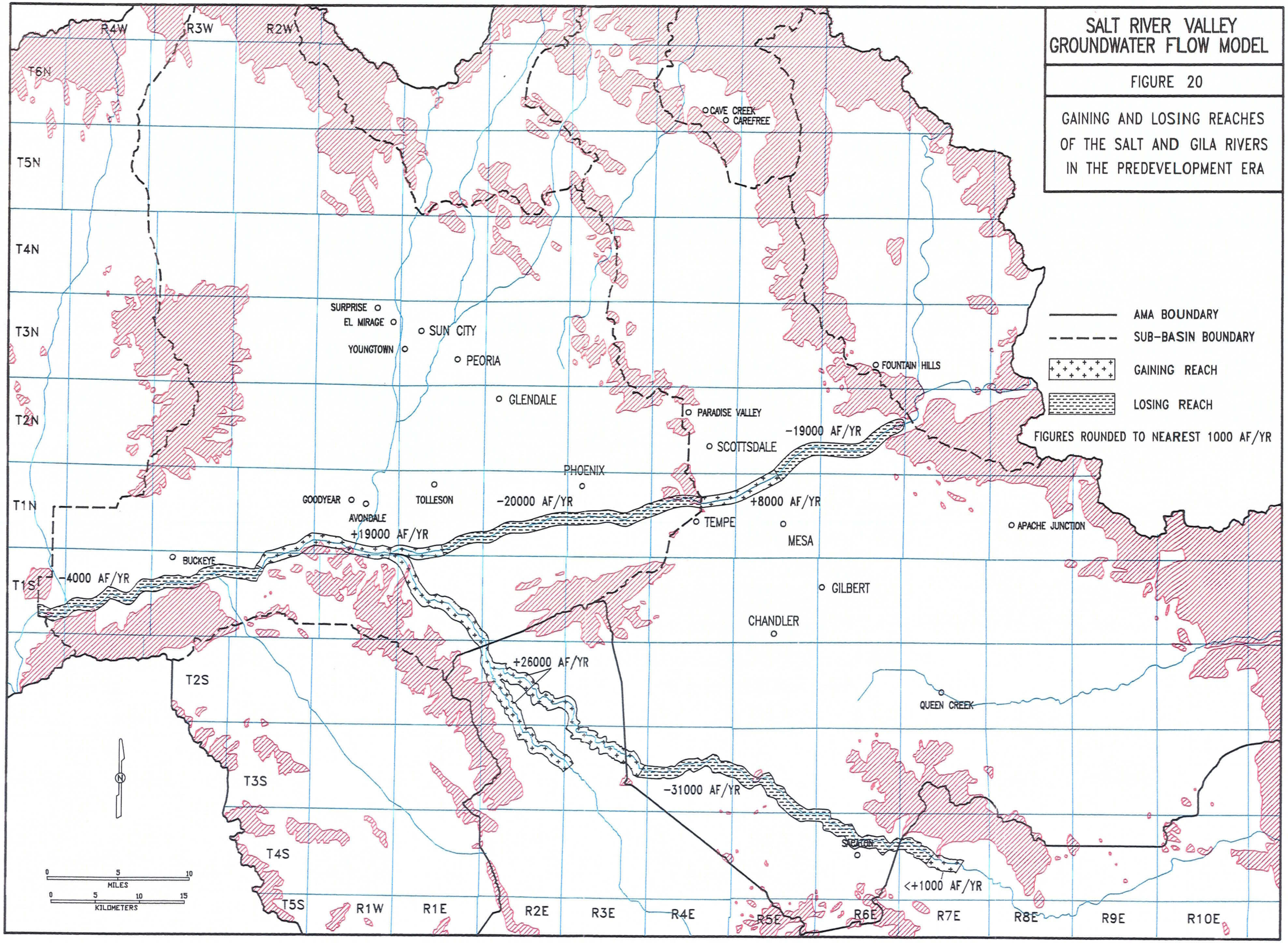
FIGURE 17

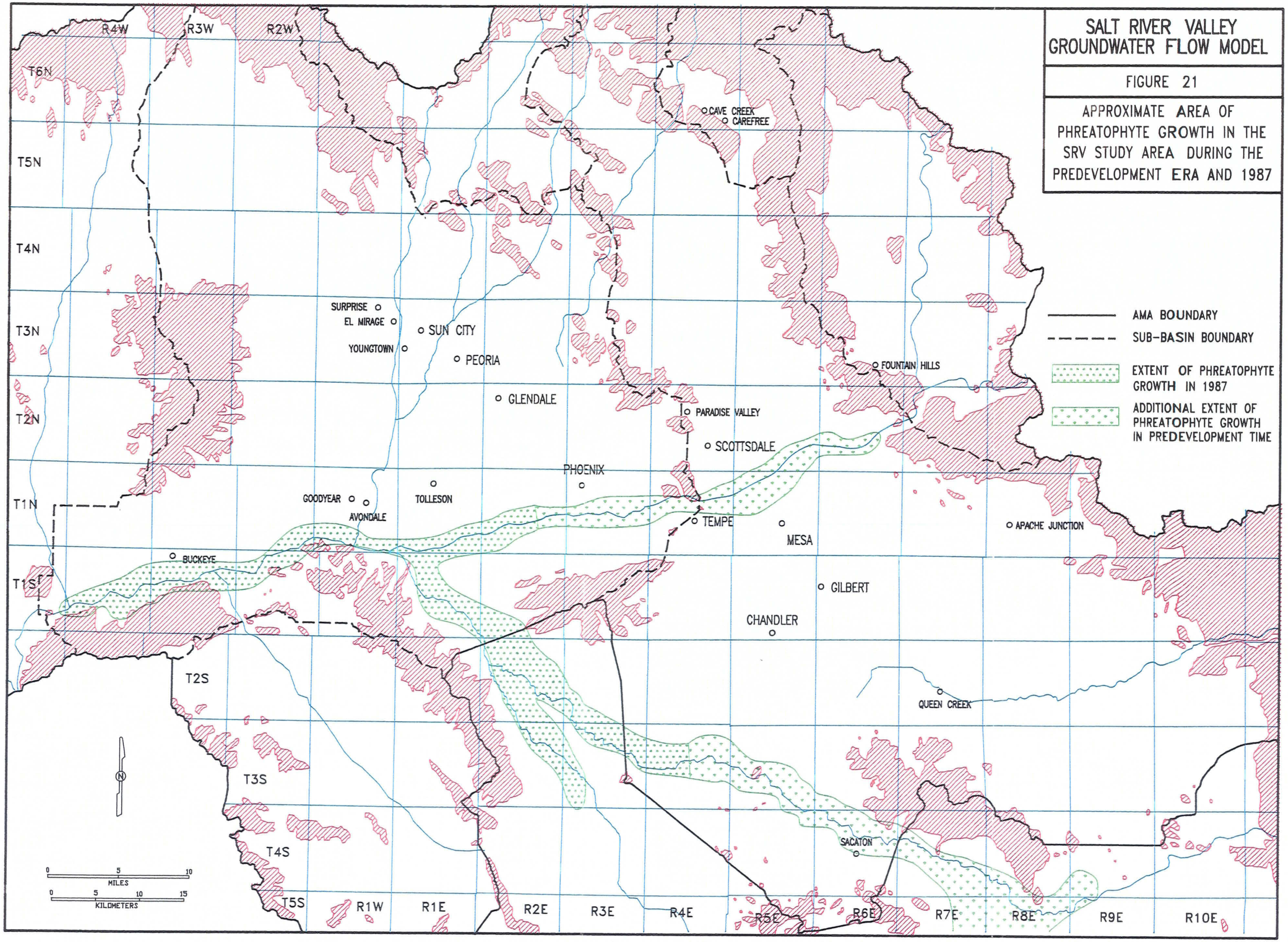
STREAM GAGING STATIONS IN THE PHOENIX AMA

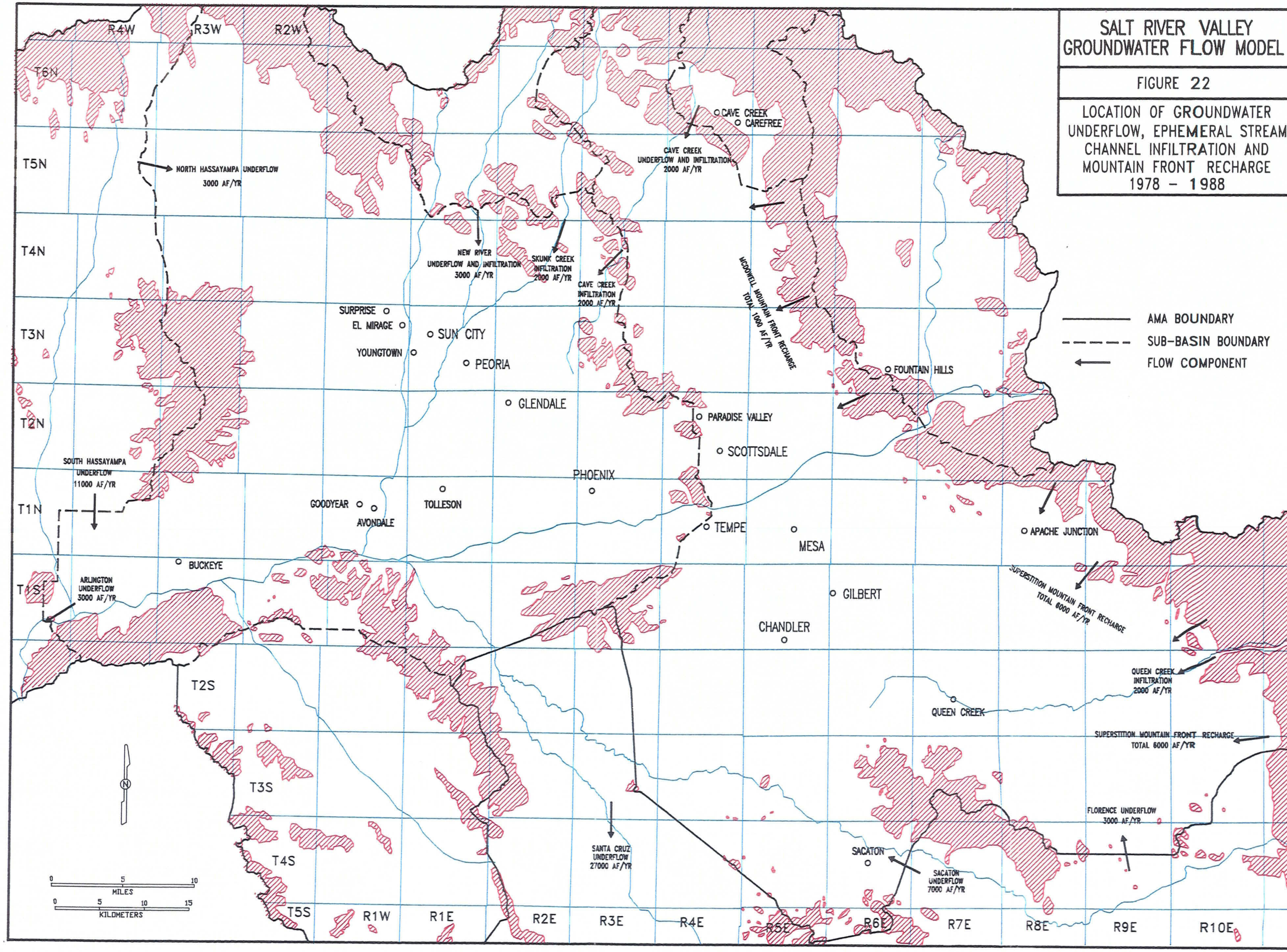


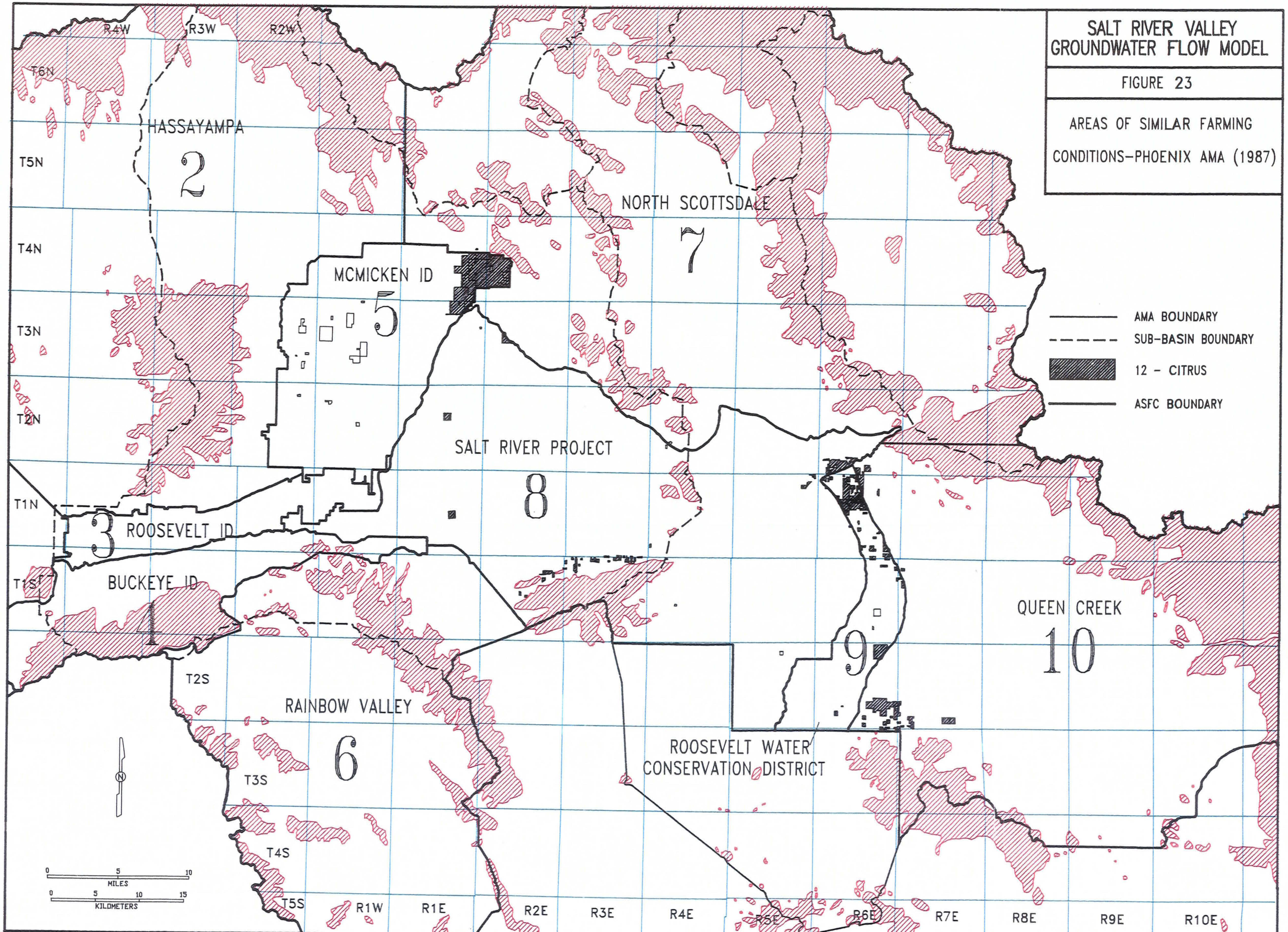

SALT RIVER VALLEY
GROUNDWATER FLOW MODEL
FIGURE 18
WATER TABLE ELEVATION
CIRCA 1900
AMA BOUNDARY
SUB-BASIN BOUNDARY
* Adapted from USGS
Predevelopment Water Level Maps:
Lee (1905)
Anderson (1968)
Thomsen and Baldys (1985)
R4W
R3W
R2W
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S
MILES
KILOMETERS


SALT RIVER VALLEY
GROUNDWATER FLOW MODEL
FIGURE 19
LOCATION OF GROUNDWATER UNDERFLOW, EPHEMERAL STREAM CHANNEL INFILTRATION AND MOUNTAIN FRONT RECHARGE FOR PREDEVELOPMENT ERA
AMA BOUNDARY
SUB-BASIN BOUNDARY
FLOW COMPONENT
R4W
R3W
R2W
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S
NORTH HASSAYAMPA UNDERFLOW 3000 AF/YR
AGUA FRIA RIVER UNDERFLOW AND INFILTRATION 9000 AF/YR
NEW RIVER UNDERFLOW AND INFILTRATION 3000 AF/YR
SKUNK CREEK INFILTRATION 2000 AF/YR
CAVE CREEK INFILTRATION 2000 AF/YR
CAVE CREEK UNDERFLOW AND INFILTRATION 2000 AF/YR
CAVE CREEK
CAREFREE
MCDOWELL MOUNTAIN FRONT RECHARGE TOTAL 1000 AF/YR
FOUNTAIN HILLS
SURPRISE
EL MIRAGE
SUN CITY
YOUNGTOWN
PEORIA
GLENDALE
PARADISE VALLEY
SCOTTSDALE
PHOENIX
SOUTH HASSAYAMPA UNDERFLOW 8000 AF/YR
GOODYEAR
AVONDALE
TOLLESON
TEMPE
MESA
APACHE JUNCTION
BUCKEYE
ARLINGTON UNDERFLOW 2000 AF/YR
SUPERSTITION MOUNTAIN FRONT RECHARGE TOTAL 6000 AF/YR
GILBERT
CHANDLER
QUEEN CREEK INFILTRATION 2000 AF/YR
QUEEN CREEK
SUPERSTITION MOUNTAIN FRONT RECHARGE TOTAL 6000 AF/YR
N
FLORENCE UNDERFLOW <1000 AF/YR
SANTA CRUZ UNDERFLOW 13000 AF/YR
SACATON
SACATON UNDERFLOW 7000 AF/YR
0 5 10
MILES
0 5 10 15
KILOMETERS

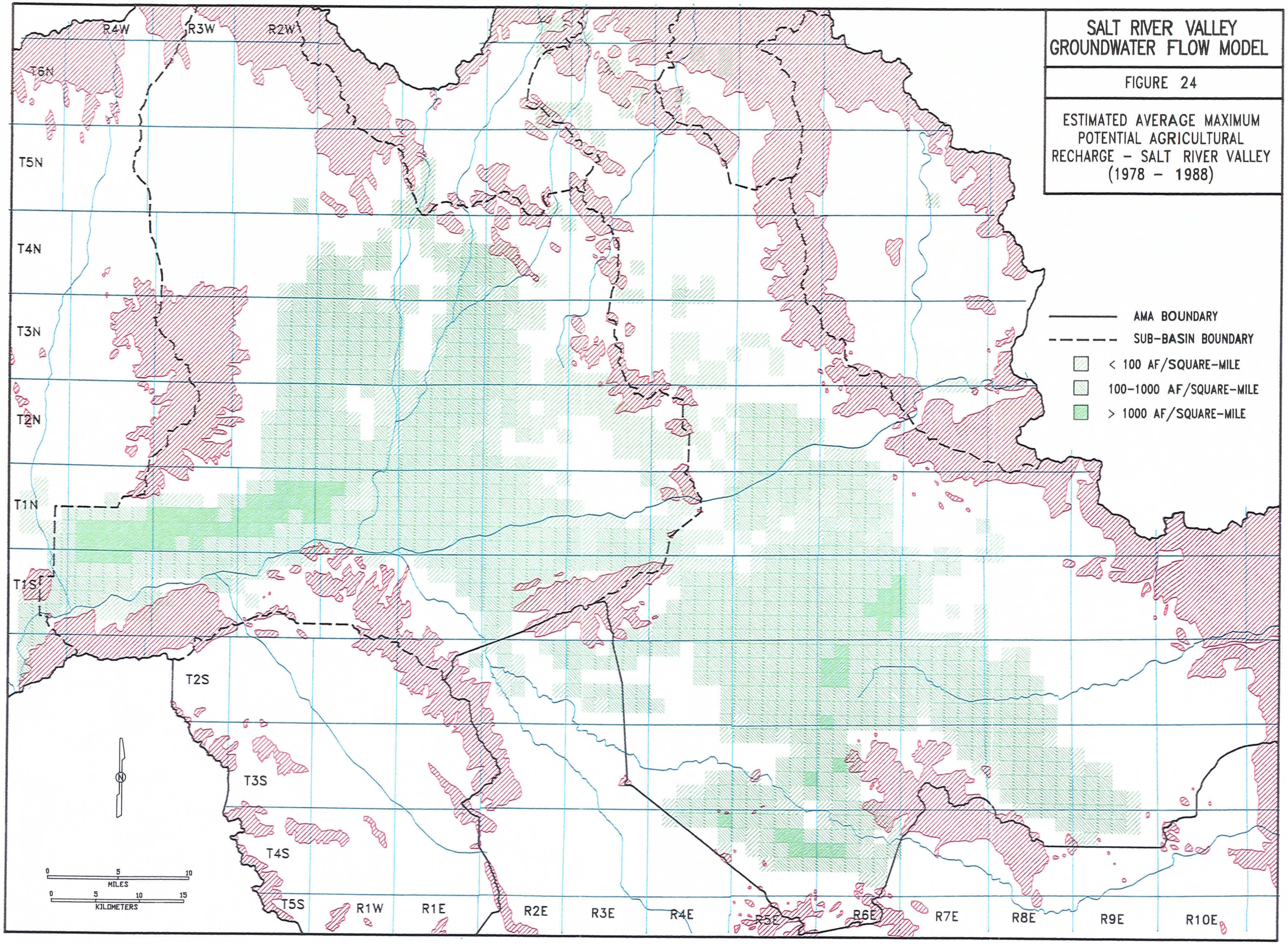

SALT RIVER VALLEY GROUNDWATER FLOW MODEL
FIGURE 20
GAINING AND LOSING REACHES OF THE SALT AND GILA RIVERS IN THE PREDEVELOPMENT ERA
AMA BOUNDARY
SUB-BASIN BOUNDARY
GAINING REACH
LOSING REACH
FIGURES ROUNDED TO NEAREST 1000 AF/YR
R4W
R3W
R2W
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
CAVE CREEK
CAREFREE
SURPRISE
EL MIRAGE
SUN CITY
YOUNGTOWN
PEORIA
GLENDALE
FOUNTAIN HILLS
PARADISE VALLEY
SCOTTSDALE
PHOENIX
GOODYEAR
AVONDALE
TOLLESON
TEMPE
MESA
APACHE JUNCTION
BUCKEYE
GILBERT
CHANDLER
QUEEN CREEK
-19000 AF/YR
-20000 AF/YR
+8000 AF/YR
+19000 AF/YR
-4000 AF/YR
+26000 AF/YR
-31000 AF/YR
<+1000 AF/YR
MILES
KILOMETERS
0
5
10
15
N

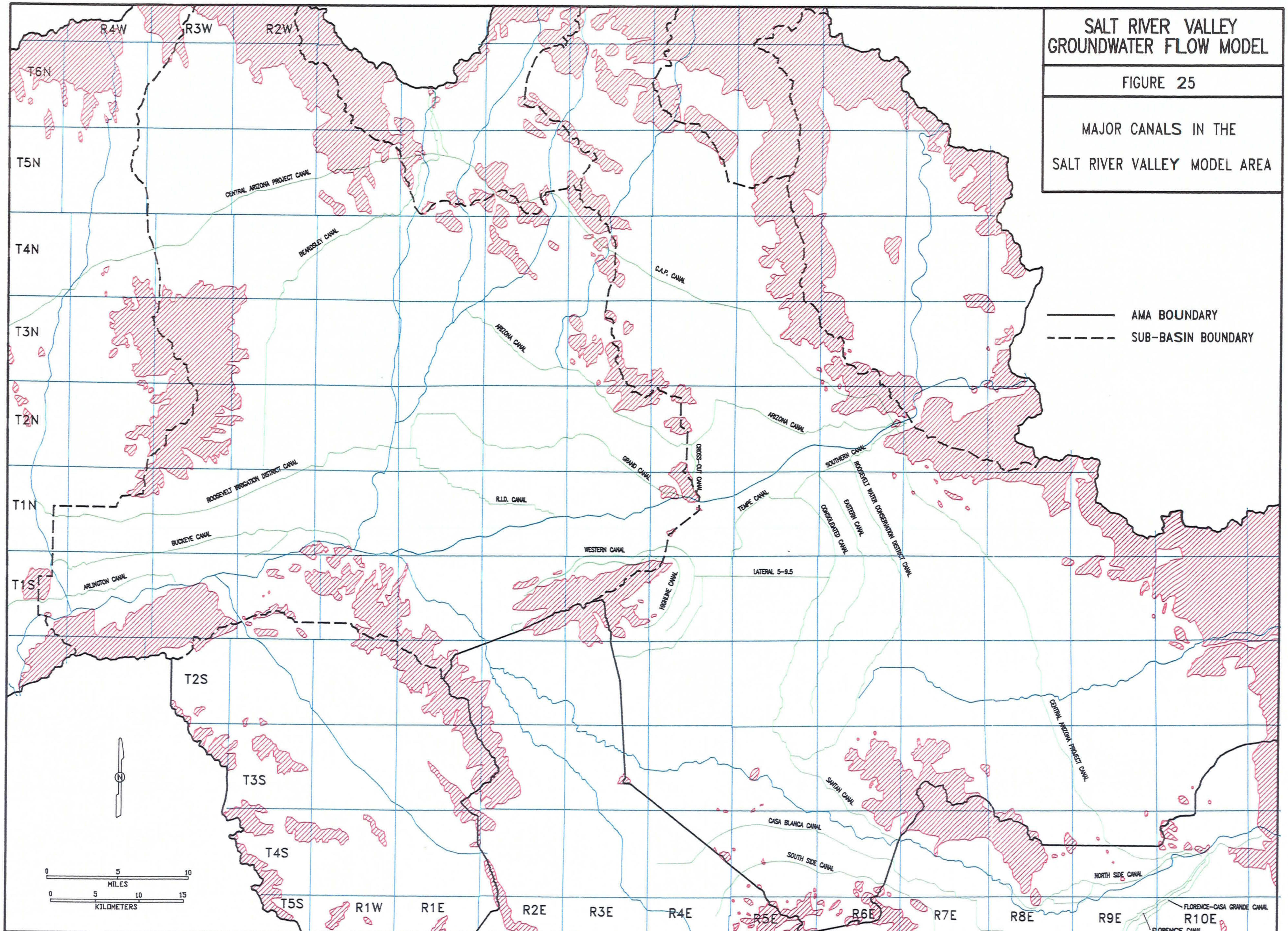

SALT RIVER VALLEY GROUNDWATER FLOW MODEL
FIGURE 21
APPROXIMATE AREA OF PHREATOPHYTE GROWTH IN THE SRV STUDY AREA DURING THE PREDEVELOPMENT ERA AND 1987
AMA BOUNDARY
SUB-BASIN BOUNDARY
EXTENT OF PHREATOPHYTE GROWTH IN 1987
ADDITIONAL EXTENT OF PHREATOPHYTE GROWTH IN PREDEVELOPMENT TIME
R4W
R3W
R2W
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
CAVE CREEK
CAREFREE
SURPRISE
EL MIRAGE
SUN CITY
YOUNGTOWN
PEORIA
GLENDALE
FOUNTAIN HILLS
PARADISE VALLEY
SCOTTSDALE
PHOENIX
GOODYEAR
AVONDALE
TOLLESON
TEMPE
MESA
APACHE JUNCTION
BUCKEYE
GILBERT
CHANDLER
QUEEN CREEK
SACATON
MILES
KILOMETERS
0
5
10
15


SALT RIVER VALLEY GROUNDWATER FLOW MODEL
FIGURE 22
LOCATION OF GROUNDWATER UNDERFLOW, EPHEMERAL STREAM CHANNEL INFILTRATION AND MOUNTAIN FRONT RECHARGE 1978 - 1988
AMA BOUNDARY
SUB-BASIN BOUNDARY
FLOW COMPONENT
R4W
R3W
R2W
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S
NORTH HASSAYAMPA UNDERFLOW 3000 AF/YR
SOUTH HASSAYAMPA UNDERFLOW 11000 AF/YR
ARLINGTON UNDERFLOW 3000 AF/YR
NEW RIVER UNDERFLOW AND INFILTRATION 3000 AF/YR
SKUNK CREEK INFILTRATION 2000 AF/YR
CAVE CREEK INFILTRATION 2000 AF/YR
CAVE CREEK UNDERFLOW AND INFILTRATION 2000 AF/YR
MCDOWELL MOUNTAIN FRONT RECHARGE TOTAL 1000 AF/YR
SUPERSTITION MOUNTAIN FRONT RECHARGE TOTAL 6000 AF/YR
QUEEN CREEK INFILTRATION 2000 AF/YR
SUPERSTITION MOUNTAIN FRONT RECHARGE TOTAL 6000 AF/YR
FLORENCE UNDERFLOW 3000 AF/YR
SACATON UNDERFLOW 7000 AF/YR
SANTA CRUZ UNDERFLOW 27000 AF/YR
CAVE CREEK
CAREFREE
SURPRISE
EL MIRAGE
SUN CITY
YOUNGTOWN
PEORIA
GLENDALE
PARADISE VALLEY
SCOTTSDALE
FOUNTAIN HILLS
PHOENIX
GOODYEAR
AVONDALE
TOLLESON
TEMPE
MESA
APACHE JUNCTION
BUCKEYE
GILBERT
CHANDLER
QUEEN CREEK
SACATON
N
0 5 10
MILES
0 5 10 15
KILOMETERS



SALT RIVER VALLEY
GROUNDWATER FLOW MODEL
FIGURE 23
AREAS OF SIMILAR FARMING
CONDITIONS–PHOENIX AMA (1987)
AMA BOUNDARY
SUB-BASIN BOUNDARY
12 – CITRUS
ASFC BOUNDARY
HASSAYAMPA
2
MCMICKEN ID
5
NORTH SCOTTSDALE
7
SALT RIVER PROJECT
8
3
ROOSEVELT ID
BUCKEYE ID
1
RAINBOW VALLEY
6
9
QUEEN CREEK
10
ROOSEVELT WATER
CONSERVATION DISTRICT
R4W
R3W
R2W
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
0
5
10
MILES
0
5
10
15
KILOMETERS
N


SALT RIVER VALLEY
GROUNDWATER FLOW MODEL
FIGURE 24
ESTIMATED AVERAGE MAXIMUM
POTENTIAL AGRICULTURAL
RECHARGE - SALT RIVER VALLEY
(1978 - 1988)
AMA BOUNDARY
SUB-BASIN BOUNDARY
< 100 AF/SQUARE-MILE
100-1000 AF/SQUARE-MILE
> 1000 AF/SQUARE-MILE
R4W
R3W
R2W
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
T5S
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
N
0 5 10
MILES
0 5 10 15
KILOMETERS



SALT RIVER VALLEY GROUNDWATER FLOW MODEL

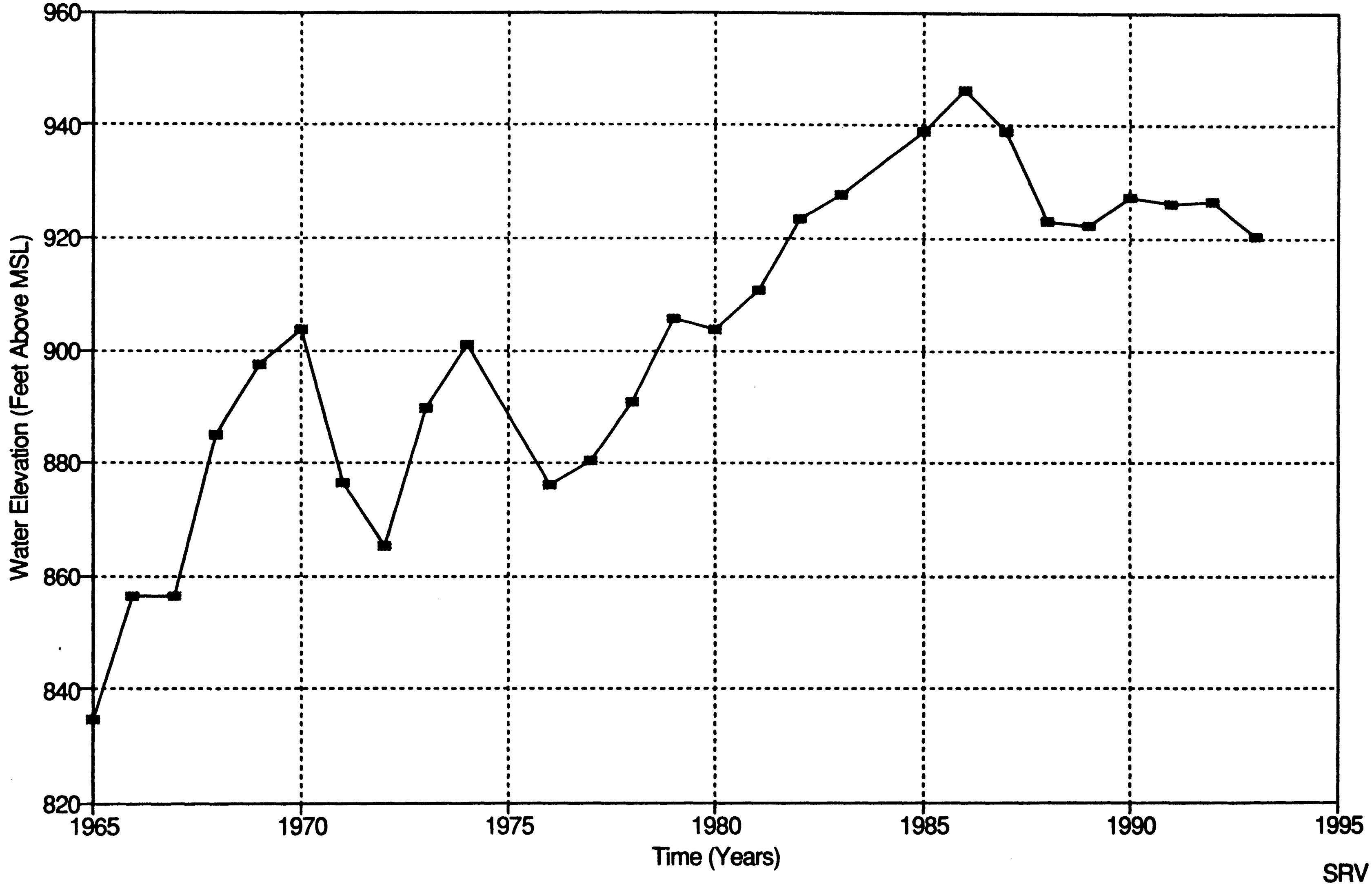
FIGURE 25

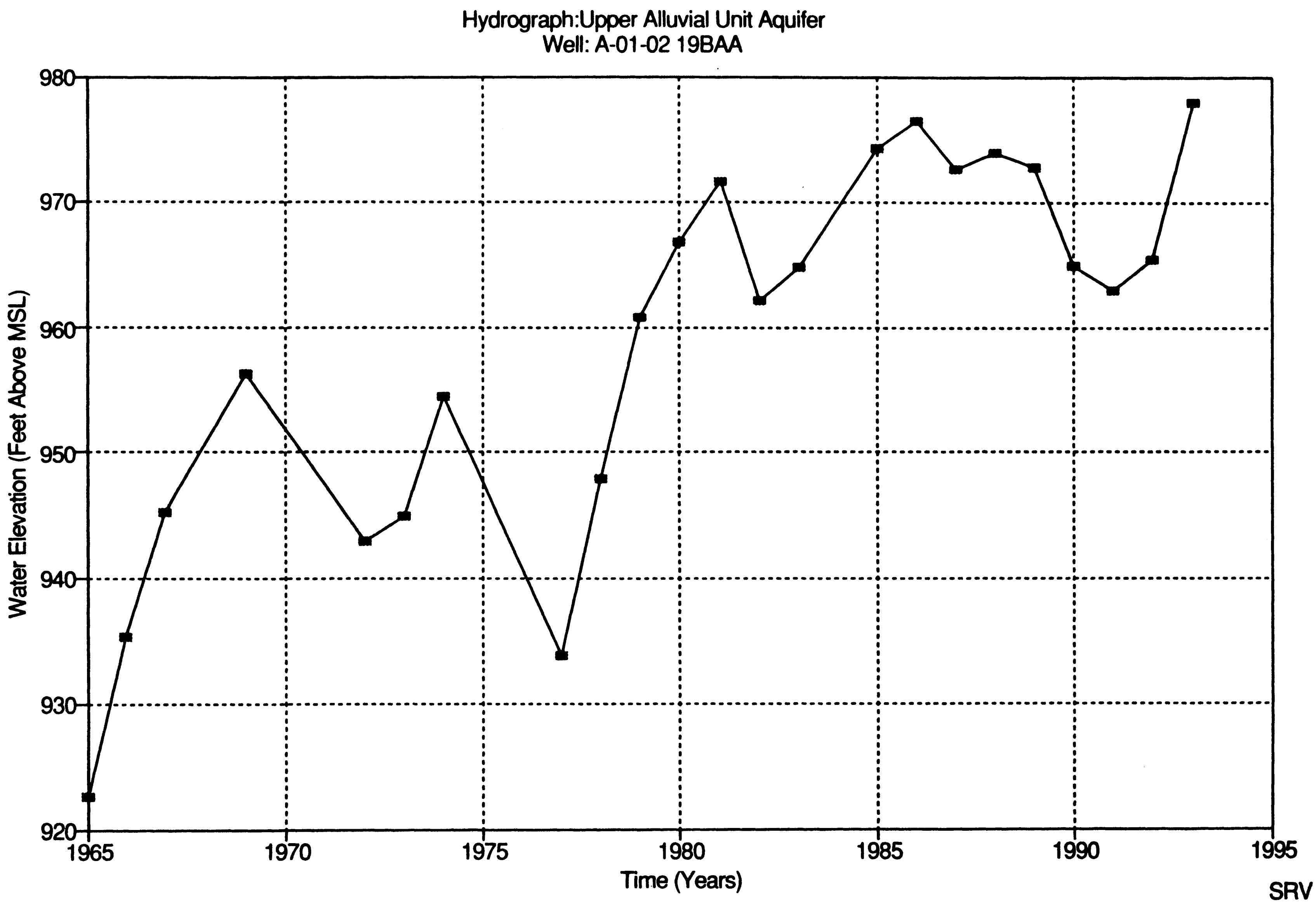
MAJOR CANALS IN THE SALT RIVER VALLEY MODEL AREA

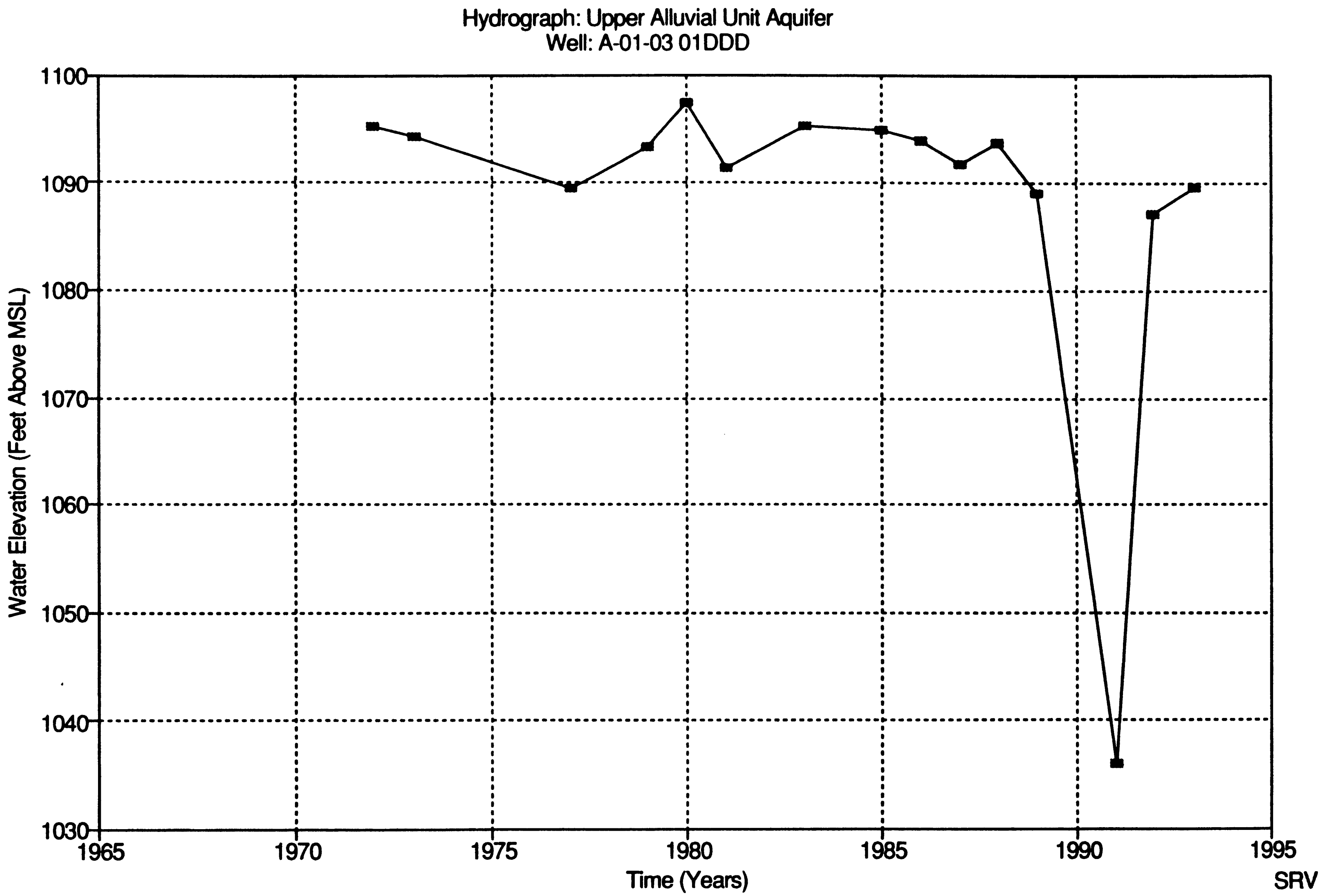
Appendix II

Hydrographs

Hydrograph:Upper Alluvial Unit Aquifer
Well: A-01-01 04AAA2

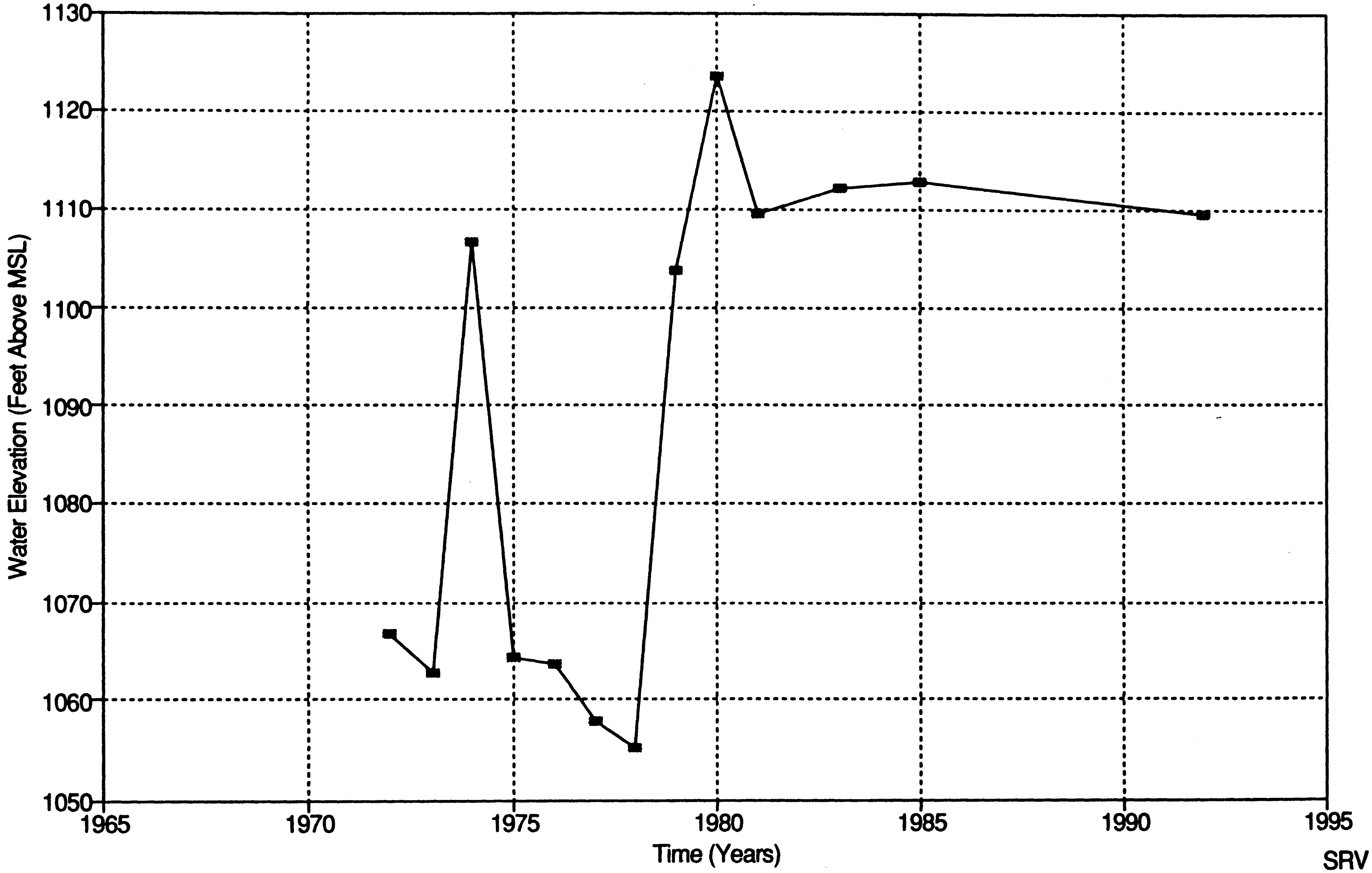



Hydrograph:Upper Alluvial Unit Aquifer
Well: A-01-02 19BAA
Water Elevation (Feet Above MSL)
980
970
960
950
940
930
920
1965
1970
1975
1980
1985
1990
1995
Time (Years)
SRV

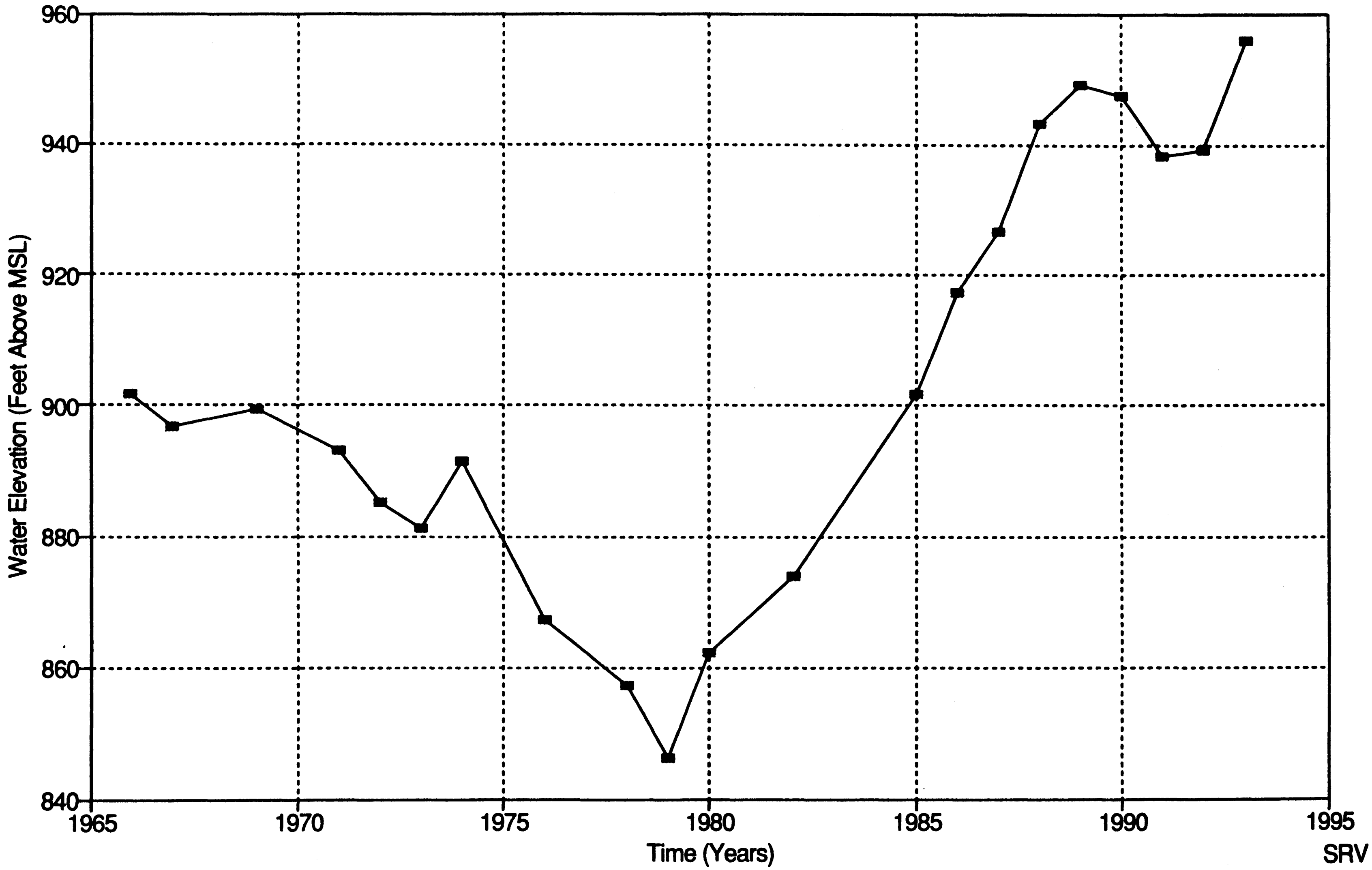


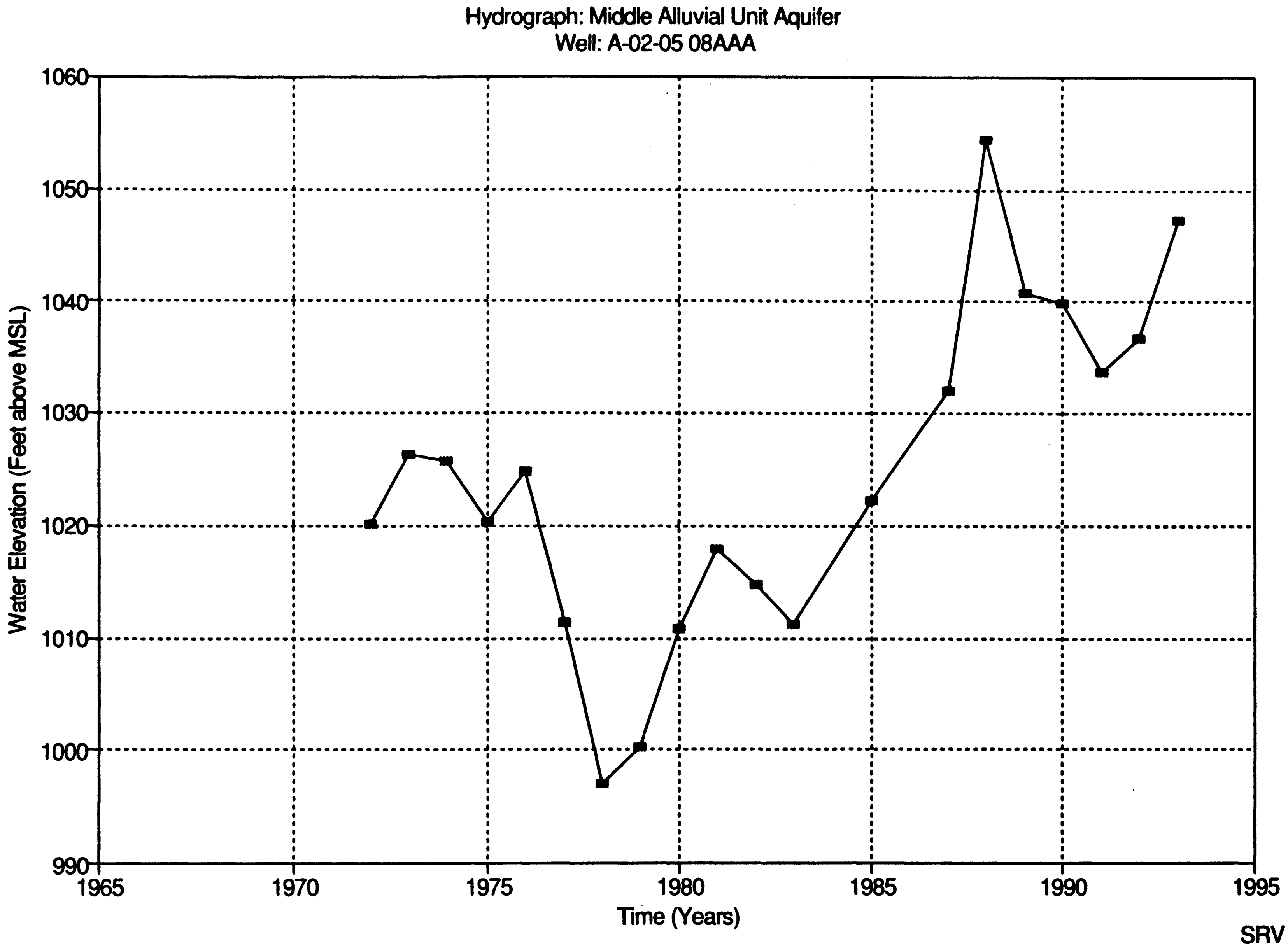
Hydrograph: Upper Alluvial Unit Aquifer
Well: A-01-03 01DDD
1100
1090
1080
1070
1060
1050
1040
1030
1965
1970
1975
1980
1985
1990
1995
Water Elevation (Feet Above MSL)
Time (Years)
SRV

Hydrograph:UAU/MAU Unit Aquifer
Well: A-01-05 07BAA

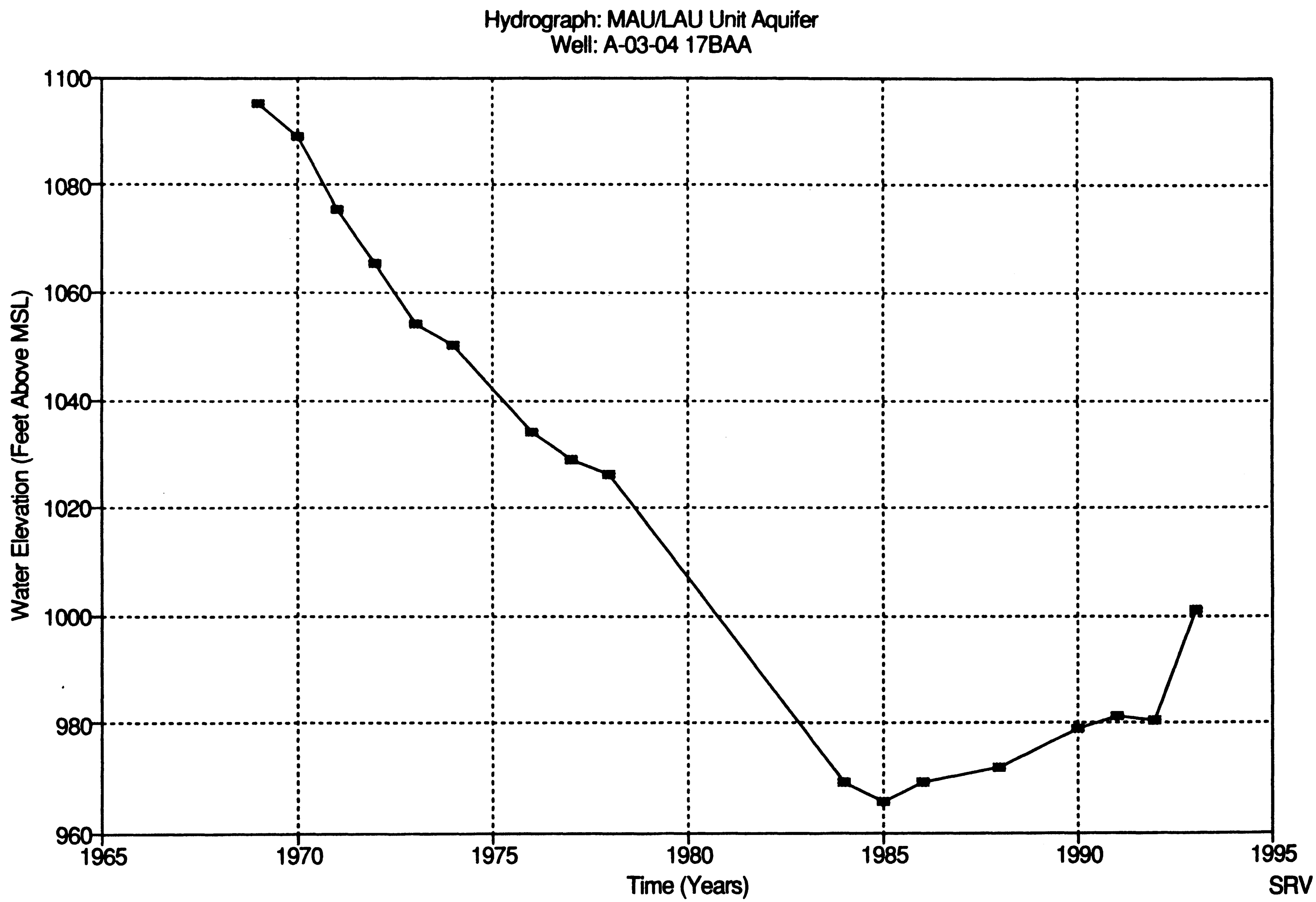


Hydrograph:Middle Alluvial Unit Aquifer
Well: A-01-06 14AAA2

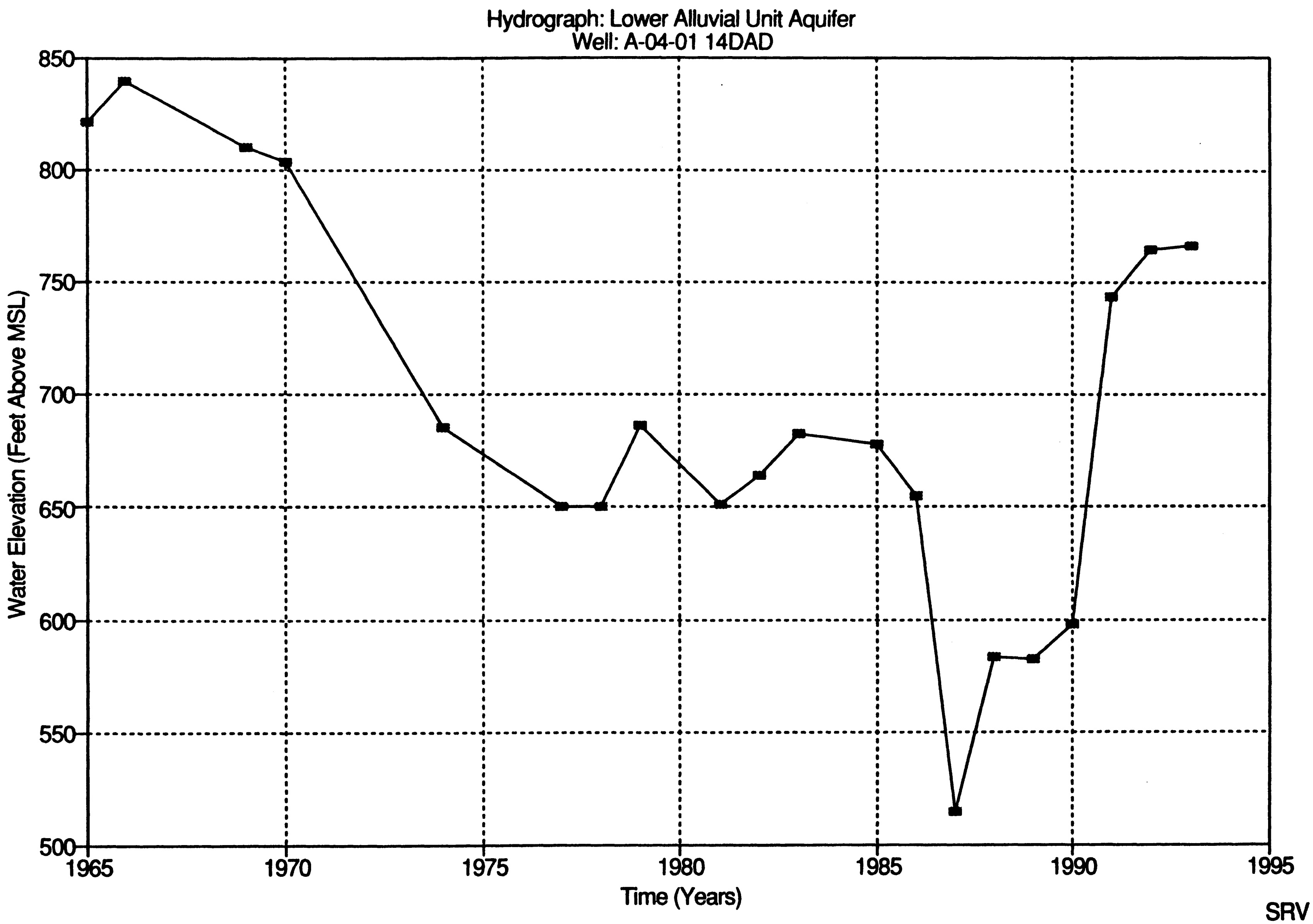




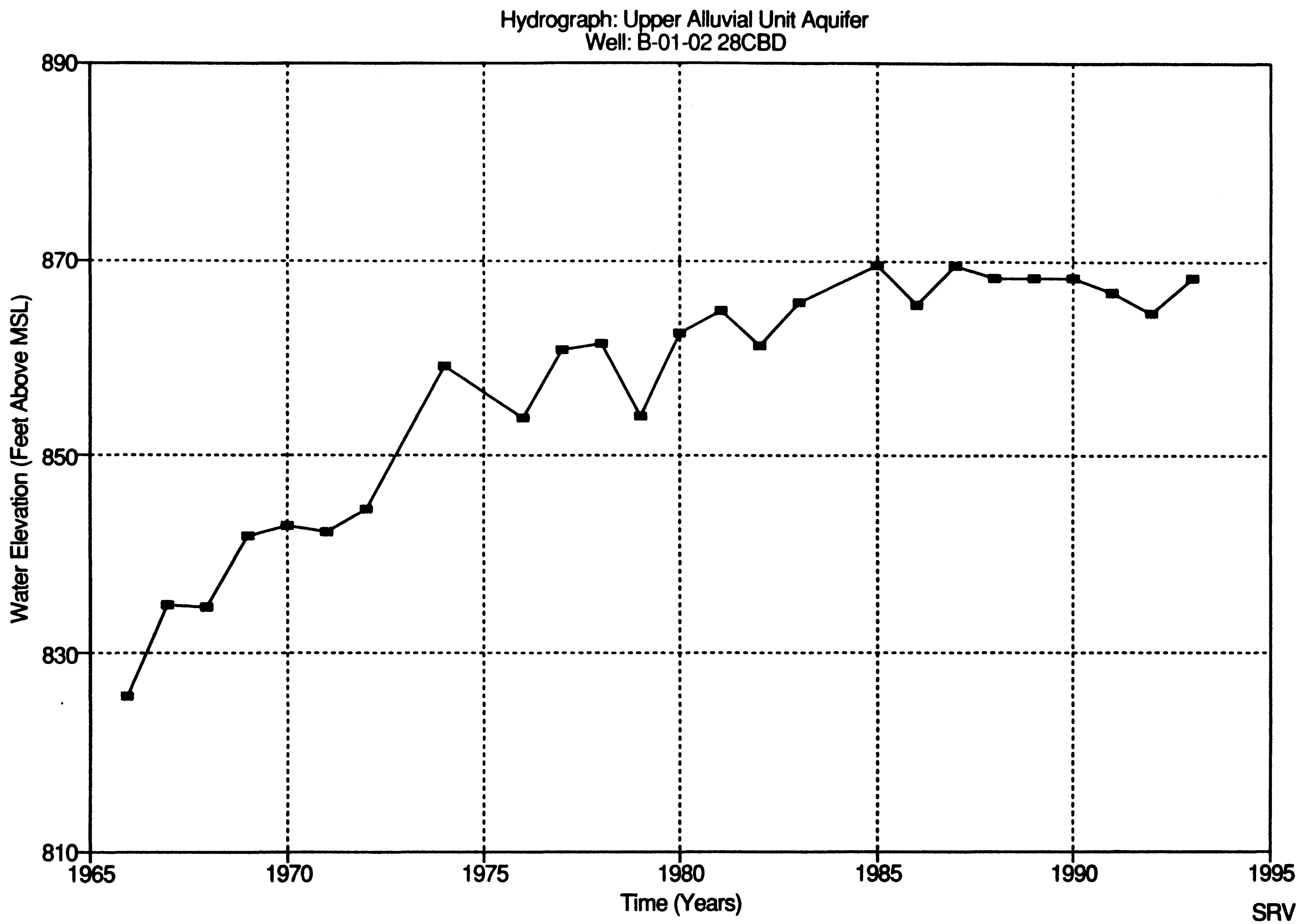
Hydrograph: Middle Alluvial Unit Aquifer
Well: A-02-05 08AAA
Water Elevation (Feet above MSL)
1060
1050
1040
1030
1020
1010
1000
990
1965
1970
1975
1980
1985
1990
1995
Time (Years)
SRV



Hydrograph: MAU/LAU Unit Aquifer
Well: A-03-04 17BAA
Water Elevation (Feet Above MSL)
1100
1080
1060
1040
1020
1000
980
960
1965
1970
1975
1980
1985
1990
1995
Time (Years)
SRV



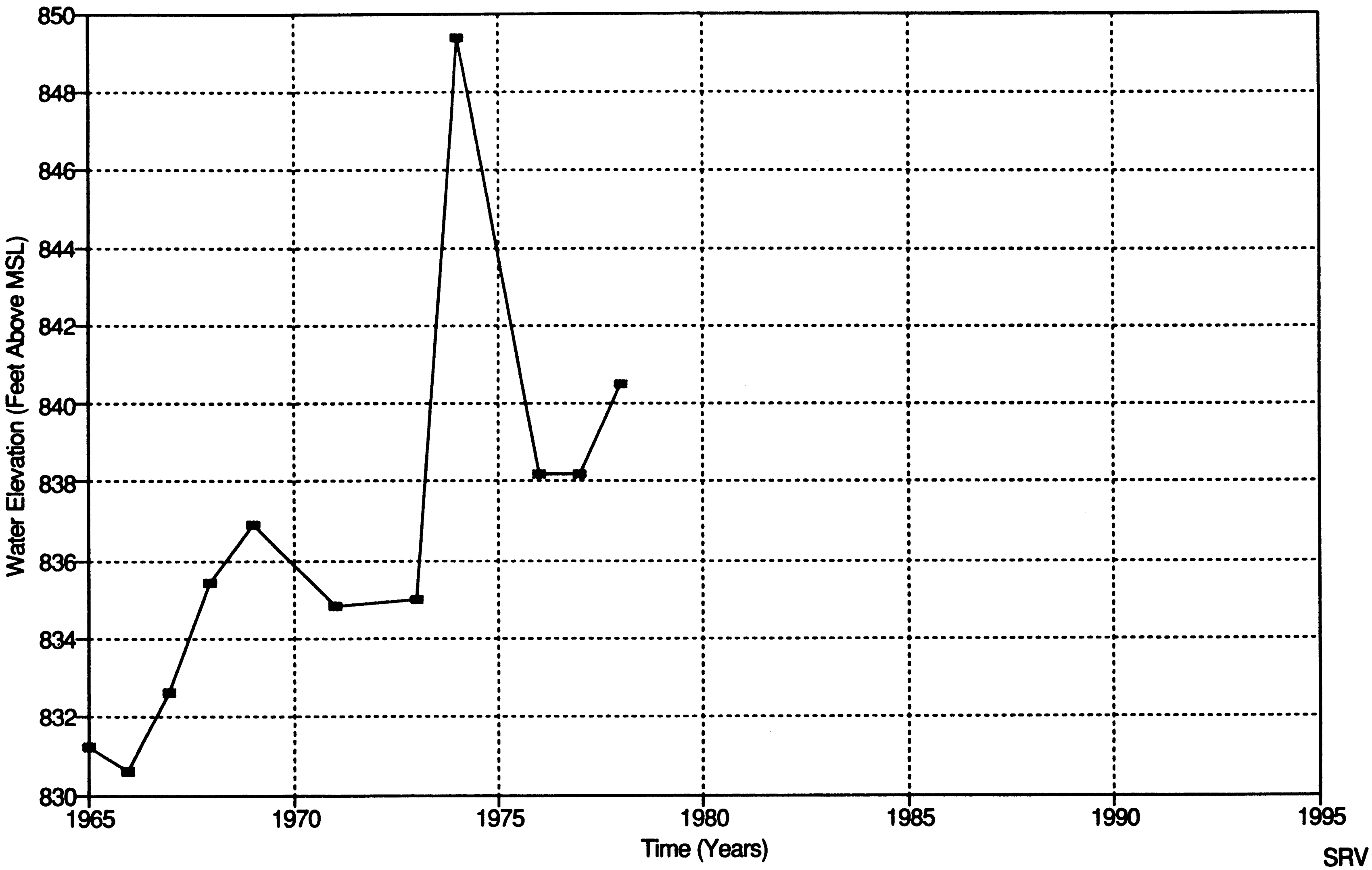
Hydrograph: Lower Alluvial Unit Aquifer
Well: A-04-01 14DAD
Water Elevation (Feet Above MSL)
850
800
750
700
650
600
550
500
1965
1970
1975
1980
1985
1990
1995
Time (Years)
SRV

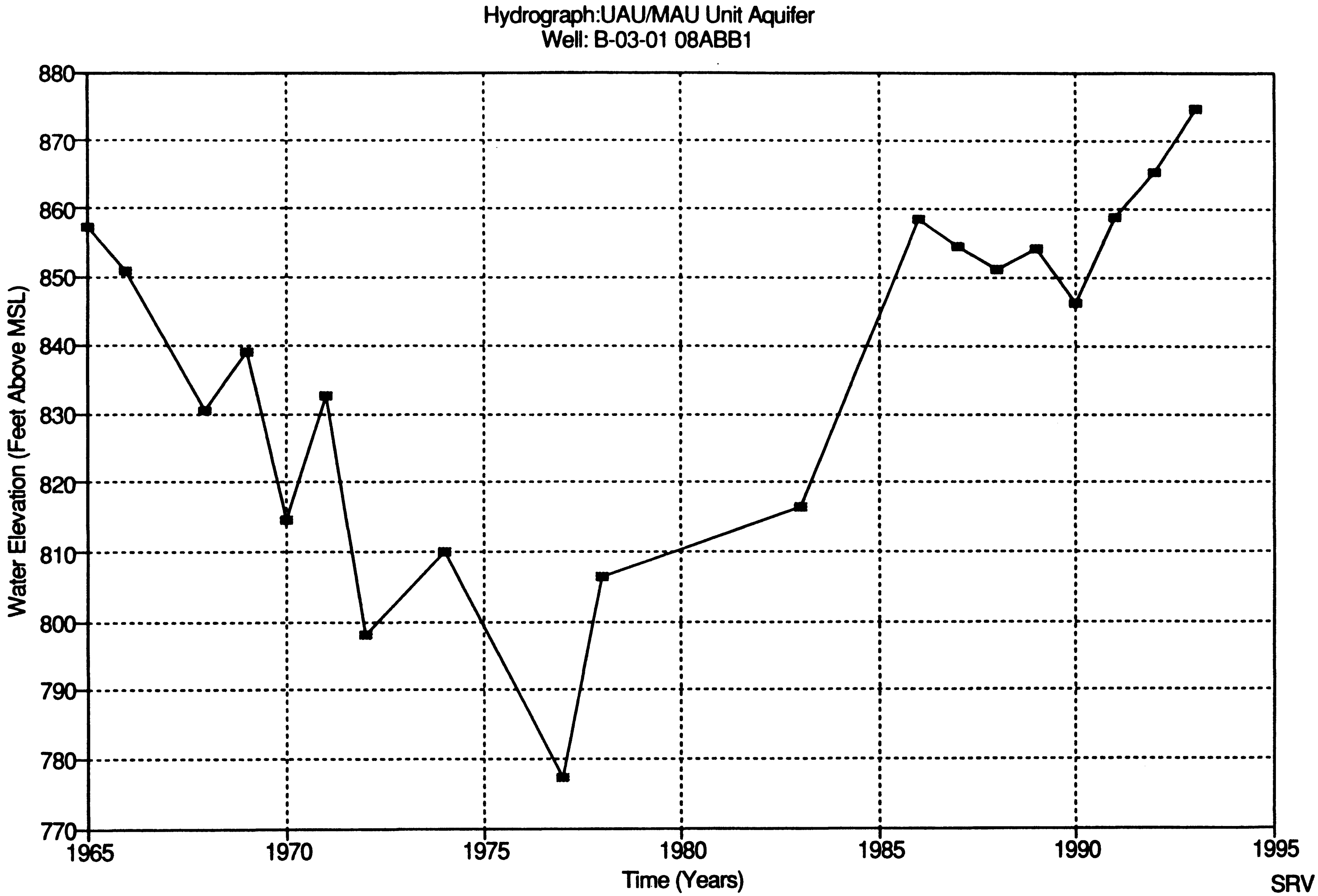

Hydrograph: Upper Alluvial Unit Aquifer
Well: B-01-02 28CBD
890
870
850
830
810
Water Elevation (Feet Above MSL)
1965
1970
1975
1980
1985
1990
1995
Time (Years)
SRV

Hydrograph:Middle Alluvial Unit Aquifer
Well: B-01-02 36BBC

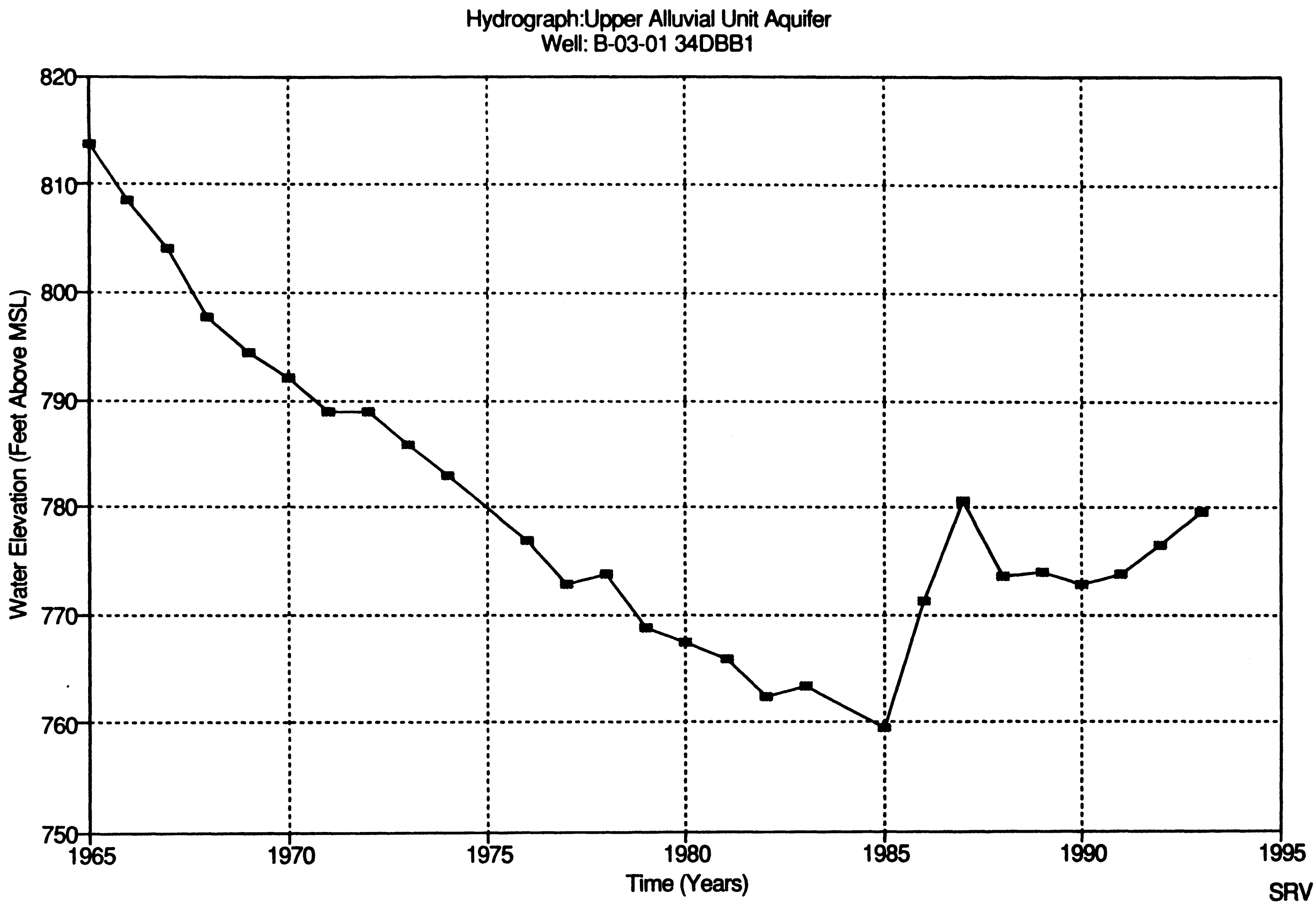
SRV

Hydrograph:Upper Alluvial Unit Aquifer
Well: B-01-04 27ABB

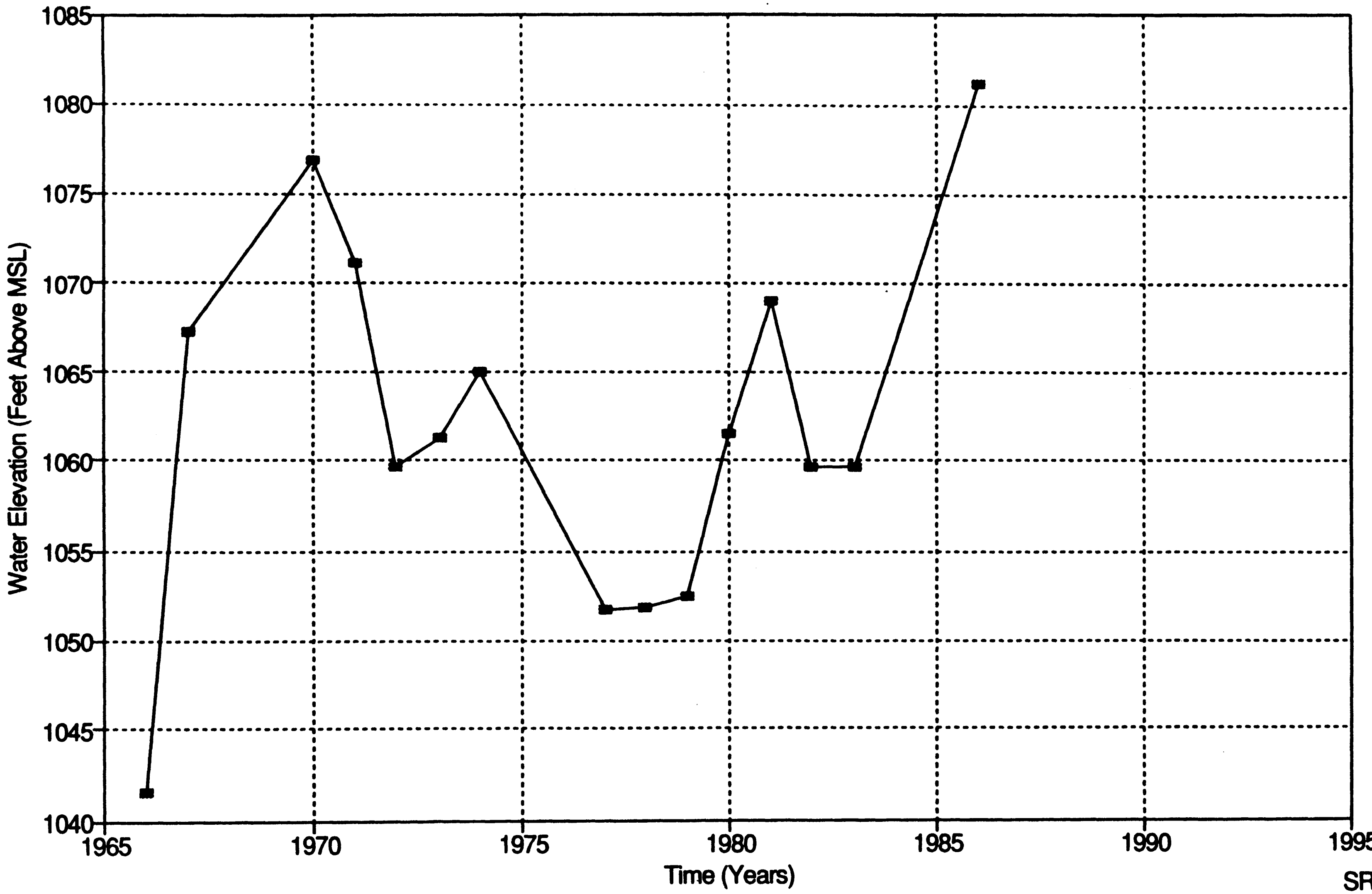




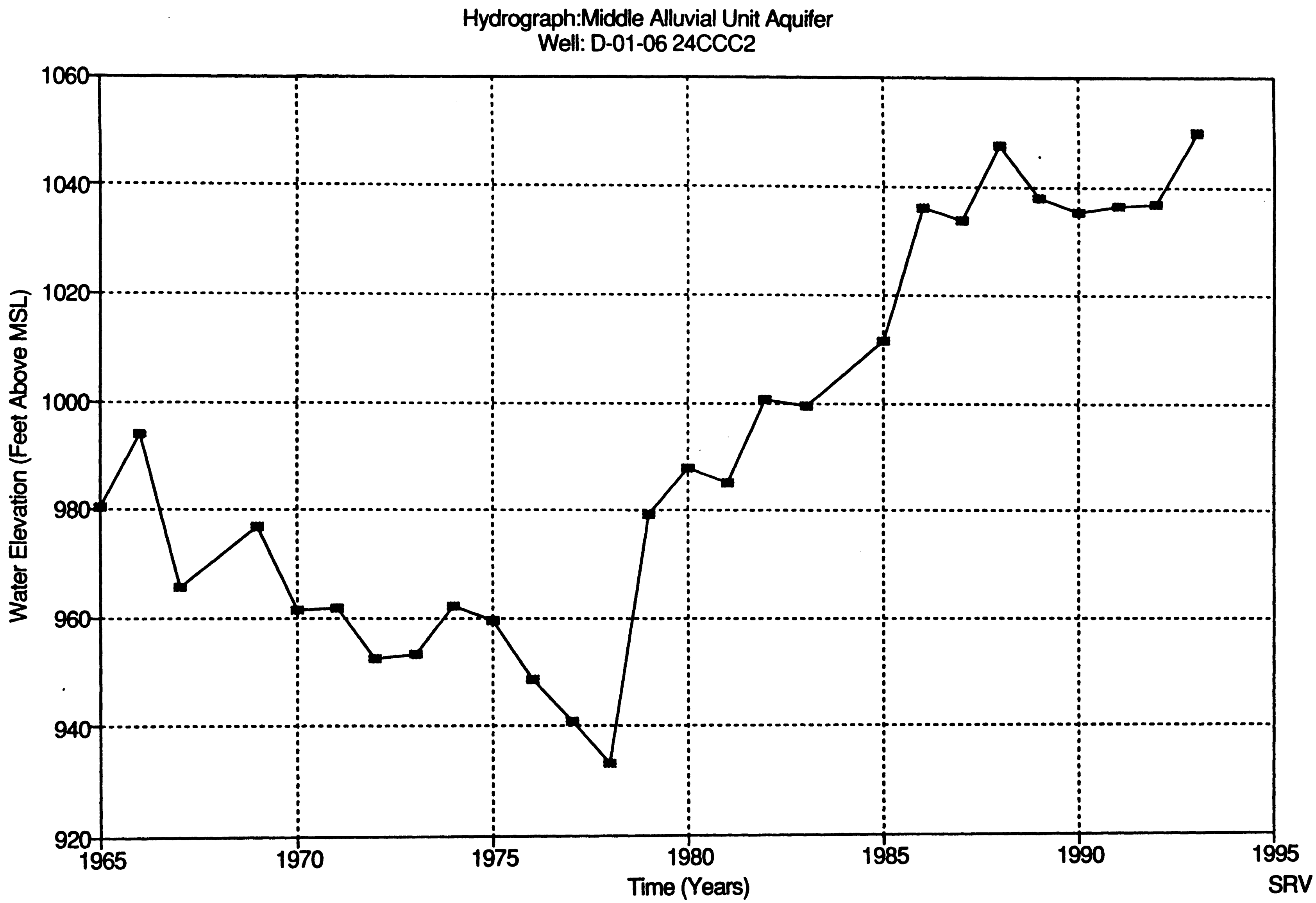
Hydrograph:UAU/MAU Unit Aquifer
Well: B-03-01 08ABB1
Water Elevation (Feet Above MSL)
880
870
860
850
840
830
820
810
800
790
780
770
1965
1970
1975
1980
1985
1990
1995
Time (Years)
SRV

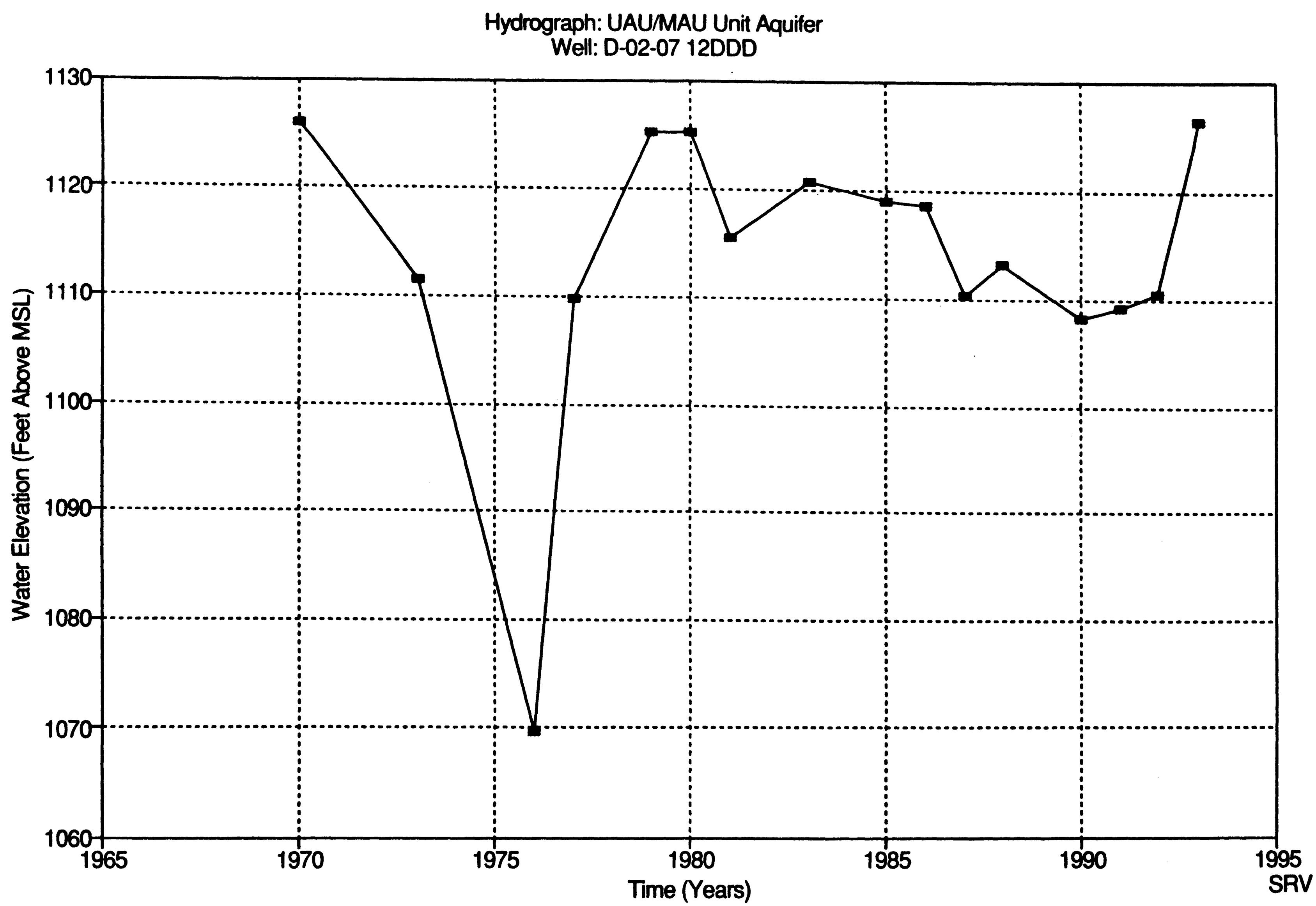

Hydrograph:Upper Alluvial Unit Aquifer
Well: B-03-01 34DBB1
Water Elevation (Feet Above MSL)
820
810
800
790
780
770
760
750
1965
1970
1975
1980
1985
1990
1995
Time (Years)
SRV

Hydrograph:Middle Alluvial Unit Aquifer
Well: D-01-05 29BAD



SRV


Hydrograph:Middle Alluvial Unit Aquifer
Well: D-01-06 24CCC2
Water Elevation (Feet Above MSL)
1060
1040
1020
1000
980
960
940
920
1965
1970
1975
1980
1985
1990
1995
Time (Years)
SRV


Hydrograph: UAU/MAU Unit Aquifer
Well: D-02-07 12DDD
Water Elevation (Feet Above MSL)
1130
1120
1110
1100
1090
1080
1070
1060
1965
1970
1975
1980
1985
1990
1995
Time (Years)
SRV